DESIGNING SMART ARTIFACTS FOR ADAPTIVE MEDIATION OF SOCIAL VISCOSITY: TRIADIC ACTOR-NETWORK ENACTMENTS AS A BASIS FOR INTERACTION DESIGN

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ABSTRACT

With the advent of ubiquitous computing, interaction design has broadened its object of inquiry into how smart computational artifacts inconspicuously act in people's everyday lives. Although user-centered design approaches remain useful for exploring how people cope with interactive systems, they cannot explain how this new breed of artifacts participates in people's sociality. User-centered design approaches assume that humans control interactive systems, disregarding the agency of smart artifacts.

Based on Actor-Network Theory, this research recognizes that artifacts and humans share the capacity of influencing society and meshing with each other, constituting hybrid social actors. From that standpoint, the research offers a triadic structure of networked social interaction as a methodological basis to investigate how smart devices perceive their social setting and adaptively mediate people's interactions within activities.

These triadic units of analysis account for the interactions within and between human-nonhuman collectives in the actor-network. The *within interactions* are those that hold together humans and smart artifacts inside a collective and put forward the collective's assembled meaning for other actors in the network. The *between interactions* are those that occur among collectives and characterize the dominant relational model of the actor-network.

This triadic approach was modeled and used to analyze the interactions of participants in three empirical studies of social activities with communal goals, each

mediated by a smart artifact that enacted – signified – a balanced distribution of obligations and privileges among subjects.

Overall, the studies found that actor-networks exhibit a *social viscosity* that hinders people's interactions. This is because when people try to collectively accomplish goals, they offer resistance to one another. These design experiments also show that the intervention of smart artifacts can facilitate the achievement of cooperative and collaborative interaction between actors when the artifacts enact dominant moral principles which prompt the *preservation of social balance*, enhance the network's *information integrity*, and are located at the *focus of activity*.

The articulation of Actor-Network Theory principles with interaction design methods opens up the traditional user-artifact dyad towards triadic collective enactments by embracing diverse kinds of participants and practices, thus facilitating the design of enhanced sociality.

CHAPTER 1

INTRODUCTION

1.1 Design research problem

The design of everyday artifacts with capabilities of autonomous action – design of *smart artifacts* – is as a novel area of interdisciplinary practice positioned at the intersection between product design, interaction design and ubiquitous computing. My research topic is located in that intersecting area with particular interest on interpersonal interaction. It is centered around the idea of the design of artifacts-as-actors that mediate social processes through their interactions with people. The general question that motivates this research is: *How can the autonomous actions of smart artifacts facilitate social interaction?*

To respond to this question, this research adopts a post-humanist stance which frames the issues raised by social interaction within the concept of *social practice*. A social practice is an array of artifact-mediated activities which is centrally organized around a shared practical understanding of such activities' object of concern. From that standpoint, both humans and artifacts partake in a social practice as symmetrical actors. The artifacts are material mediators that bind together two or more human participants. Thus, my research question encompasses two socio-technical aspects: first, *how can autonomous artifacts mediate the mutual understanding of people when they interact*? Second, *how can the design of such artifacts promote social interaction between interrelated actors*?

1.1.1 Aspects of social interaction of interest in this research. Early to mid 20th century sociologists decomposed human interaction into frameworks that account for people's social action. Among them, Schutz offers a phenomenological explanation of interpersonal interaction, that this research uses as one of the foundations supporting its theoretical framework (Schutz, 1972). Another foundation is the sociological perspective of Actor-Network Theory (ANT) (Callon & Law, 1995; Latour, 2005), which accounts for the social and technological aspects of social practices with no deterministic privilege for neither social nor technological stances. According to ANT, both human and nonhuman parties are symmetrical social actors that articulate themselves, thereby constituting networks.

A social action and a social interaction are not the same. In this research, an *action* is regarded as social when it involves at least two people. The way participants get involved in social action can take multiple forms in which it is not required that both parties exhibit reciprocity. Someone acts socially when his/her action is addressed to other people. For instance, Goethe's famous line illustrates an action in which one of the parties is not committed: "And if I love you, what business is it of yours?" (Goethe 1795 cited by Schutz, 1972). This exemplifies the action of love, yet not seeking to affect the other person. Hence, the minimal requirement for a social action is to be other-oriented. However, an *interaction* requires more than simply other-orientation. To interact, it is necessary that the parties involved exhibit some sense of reciprocity, coordination and mutuality, and such interaction should be not only reportable but observable. In other words, the actions performed within an interaction should have the intention of affecting the other. It is possible to speak about a real sense of *us-ness* only in the scope of interaction.

In order to analyze how artifacts can mediate social interaction, it is necessary to position them within the collective of interacting participants. To do so, this research is interested in *triadic collectives* as units of analysis that regard three interacting parties – two humans and one smart artifact – as symmetrical social actors. ANT provides the theoretical-conceptual framework for such operation, because according to ANT, artifacts are regarded not merely as *things* in the conventional meaning but rather as *actors* taking part in collectives.

The social[1] is characterized as the networks of actors constituting collectives. While some collectives persist over time as institutions, others get dissolved and reconstituted recursively. As an example, violence is an undesirable form of social interaction that drives to the loss of trust and disruption of the *us* unity in a community. The potential consequences of violence in society are very different if there are firearms involved. The collective *aggressor-gun-victim* has dramatically more disruption potential than the *aggressor-victim* dyad. According to ANT, the gun acts in the interaction as a mediator. In that vein, artifacts do have significant effects on people's social actions for good or ill.

This research recognizes the potential for transformation and influence of artifacts in society and proposes a research field in which adaptive and autonomous actions

[1] *The social* accounts for the organizational dynamic and structure of a social group.

performed by smart devices, sensitive to their social setting, can benefit social interactions and collective experiences.

1.1.2 Aspects of computational artifacts and design of interest in this research. In contemporary society, computing power is everywhere and it finds its way into everyday artifacts. We need only to revisit Weiser's well known claim regarding disappearing computing (Weiser, 1991) to realize that sensors, processors and actuators are increasingly pervasive in people's lives as embedded or stand-alone devices. Initiatives such as the *Internet of Things* (Van Kranenburg, 2008), would empower the morning coffee cup, the chair, and the newspaper as a network of distributed agents with potential added value. This new breed of artifacts with augmented functionalities based on embedded computing power is known altogether as *smart artifacts*. The word *smart* simply refers to an entity that is *active, and to some extent autonomous*. Research projects in the field, such as *Tangible bits* (Ishii & Ullmer, 1997), *Things That Think* (Mindell, 2000), *DataTiles* (Rekimoto, Ullmer, & Oba, 2001) and *The Disappearing Computer* (Streitz, 2007), have expanded the interactive capabilities of computational artifacts, enabling them to support human cognition, communication or collaborative work. However, less research has been done on the topic of how the smartness in such smart artifacts can be applied to facilitate social interaction among people. The aim of this research is to explore this area and offer a valuable methodology and framework for the design of *socially apt smart artifacts*.

Although the scope of this research has coincidental touch points with artificial intelligence, its goal is located within the realm of interaction design. That is the reason why the autonomous and adaptable artifacts of interest in this research are named *smart* instead of *intelligent*.

A smart artifact is characterized by its autonomy and adaptability. On the one hand, the definition of autonomy can be summarized as a property of self-governing systems (Froese, Virgo, & Izquierdo, 2007). On the other hand, adaptability is defined as the capacity of a system to regulate its internal states in relation to its environment (De Jaegher & Di Paolo, 2007). Autonomy and adaptability are observable in living beings and partially in computational systems. In the case of computational systems, their adaptability has been proven by running programs that achieve and maintain goals under changing conditions. Although they are not considered as fully autonomous, impressive achievements on behavioral and constitutive autonomy have been attained by researchers (e.g., Bickmore & Picard, 2005; De Jaegher & Froese, 2009).

1.2 Research questions

As stated above, the general question that motivates this research is: *How can the autonomous actions of smart artifacts facilitate social interaction*? This main question encompasses *mediation* and *design for social interaction* as two sub-foci of inquiry. Hence, the following complementary research questions are formulated:

- How can smart artifacts mediate the mutual understanding of people when they interact?
- How can the design attributes of smart artifacts promote social interaction between interacting actors?

- From a designer's standpoint, there is an additional motivation for this research: What are the methodological implications of ascribing autonomy and adaptability as properties of everyday artifacts?

1.3 Research aim and goals

The primary aim of this research is to suggest how smart artifacts can be sensitive to the social setting in which they participate in order to enable social interaction.

The specific goals of this research are aligned to the research questions as follows:

- To propose a theoretical and methodological framework for the design of smart artifacts as mediators of social interaction.

- To extend philosophical foundations that have grounding in phenomenology as a basis for interaction analysis of and design for triadic relations of human-nonhuman-human agents

- To propose metrics to assess how social interaction may be mediated by computational technology, specifically with the advent of smart artifacts.

1.4 Research situated in the design field

This research is situated within the realm of interaction design. When engineers and designers first developed the computer as a consumer product, the object of inquiry of interaction design was how to make such machine understandable and actionable for lay people (Preece, Rogers, & Sharp, 2002). Since then, the most prominent methodological approaches are based on human cognition, psychology, language and action (Norman & Draper, 1986; Winograd, 1996; Winograd & Flores, 1987). After Weiser's claim of the 'disappearing computing,' the problem of designing usable computer interfaces was blended with the problem of how artifacts actually participate in people's everyday lives. As a result, the object of inquiry of interaction design was extended to how to design computational artifacts that inconspicuously fit people's everyday lifes (Moggridge, 2007). The user-centered design approach remains useful to study how people cope with the world, but it falls short for explaining how artifacts participate in people's sociality.

Preece *et al.* (2002) contend that interaction design has also been shifting its scope from the field of human-computer interaction (HCI) towards computer-supported cooperative work (CSCW), as a response to the concern about collaborative uses of computational tools. Although major interest in CSCW gravitates around the topic of work, distributed teams and networked collaborative projects, its scope has broadened to the social uses of technology beyond workplaces (Grudin, 2010). It is necessary to complement the user-centered approach, which is highly biased towards usability and efficiency metrics, with socially-centered approaches supporting consensus, sociality and mutuality, as well as with ludic-centered approaches with open ended interpretation results (William Gaver *et al.*, 2004). The CSCW and Intelligent User Interface (IUI) communities have topics of interest that intersect with the topic of this research in that their focus is not so much to make the computer smart unto itself, but to make the interaction between computers and people smarter. However this research regards the topic of materially mediated human interaction from a post-humanist perspective.

The problem posed in this research falls within the contemporary object of inquiry of interaction design because it explores how computers get implicitly involved in people's interpersonal interaction. Such areas of design research have been explored from several perspectives. As an example, Gaver (2007) and Dunne and Raby (2001) have conducted outstanding research on the social and pleasurable aspects of interaction design. Artists have also made a tremendous contribution to the field, either by exploring the expressiveness of digital media or by translating traditional art languages into the new media. Context-sensitive video projections and crowd-sourced installations, such as Lozano-Hemmer's Relational Architectures (Lozano-Hemmer, 1999), are instances of the quest for enticing inter-relations between computer-based art, the audience and the context.

This research aims at complementing the user-centered design approach with a theoretical framework for the design of smart artifacts which take part in people's sociality. If a smart artifact is defined as a social actor with adaptable programs-of-action, then the interacting human party can be repositioned from being the *user* of the system to being a *participant* in a new kind of collective constituted by triads of human-nonhuman-human agents.

The contributions of this research are a theoretical framework for the study of materially mediated social interaction, a series of propositions for the design of smart artifacts, and a methodological approach for the design of such artifacts. The contributions are particularly addressed to designers, engineers and product planners who seek to understand the role of interconnected computational artifacts mediating processes of social exchange. Such an outcome is also relevant for ubiquitous computing researchers and practitioners, especially those interested in the development of social interaction by tangible means.

CHAPTER 2

FOUNDATIONAL CONCEPTS ON SOCIAL AGENCY AND HUMAN-WORLD INTERACTION

This chapter presents a review of the philosophies, concepts and ideas that contribute to the understanding of social interaction from diverse fields of knowledge. The following sections offer a comprehensive literature review of concepts of *interaction* in the fields of social sciences, biology of cognition, and artificial intelligence. This review augments those concepts by examining the notion of agency together with two distinct positions concerning social agency: artificial agency, and human agency.

Among the concepts introduced in this chapter, *enactivism* offers a solid conceptual framework to determine the essential attributes of an agent and its appropriate modeling. However, the applicability of this framework in human agency does not yet cover the actual complexity of human society. The enactivist research agenda is a promising work-in-progress to which complementary socio-cultural frameworks are currently being articulated, developed, and evaluated in order to consolidate it in the study of *the social*. On the other hand, sociological theories based on interactionism and phenomenology share conclusions with the ones achieved by enactivism. These approaches are particularly interested in the human experience in the world, but do not necessarily embrace artificial agency as constitutive of *the social*. Moreover, other sociological branches displace humans from the central position of contemporary society and contemplate human-nonhuman collectives as the appropriate constitutive units that give account for a sociality with *artifacts*.

The very notion of artifact is also discussed here. If we are to think seriously about understanding how sociality is shared with artifacts, alternative understandings of what artifacts are and what they do in society needs to be considered. Commodities and instruments are two traditional concepts that form the definition of artifact in terms of products of the market place or components of our equipment toolbox. Any sociality emerging from those concepts will evolve pointing towards the notions of economic value and pragmatic utility. Design theory understands this well, and designers have successfully implemented this understanding as products and services. But this literature review is structured in a different conceptual perspective and does not intend to contradict nor controvert a designerly understanding of artifacts. This research features ideas that invite us to regard the artificial world that surrounds us from the perspective of a designer interested in using artifacts as means for social exchange, adaptive signs for solidarity, or *equipment* for cooperation.

This chapter aims to frame a theoretical foundation about social interaction and social mediators. The following chapter elaborates on such theoretical foundation and proposes a conceptual platform for the design of smart mediators of human sociality. The line of argumentation unfolds as the question of 'what is *the social?'* is elucidated, not only as a human phenomenon but also as the result of collective interaction of human and nonhuman actors. In the second half of this chapter, the line of argumentation is directed towards the role of artifacts in social action, concluding with some definitions of agency.

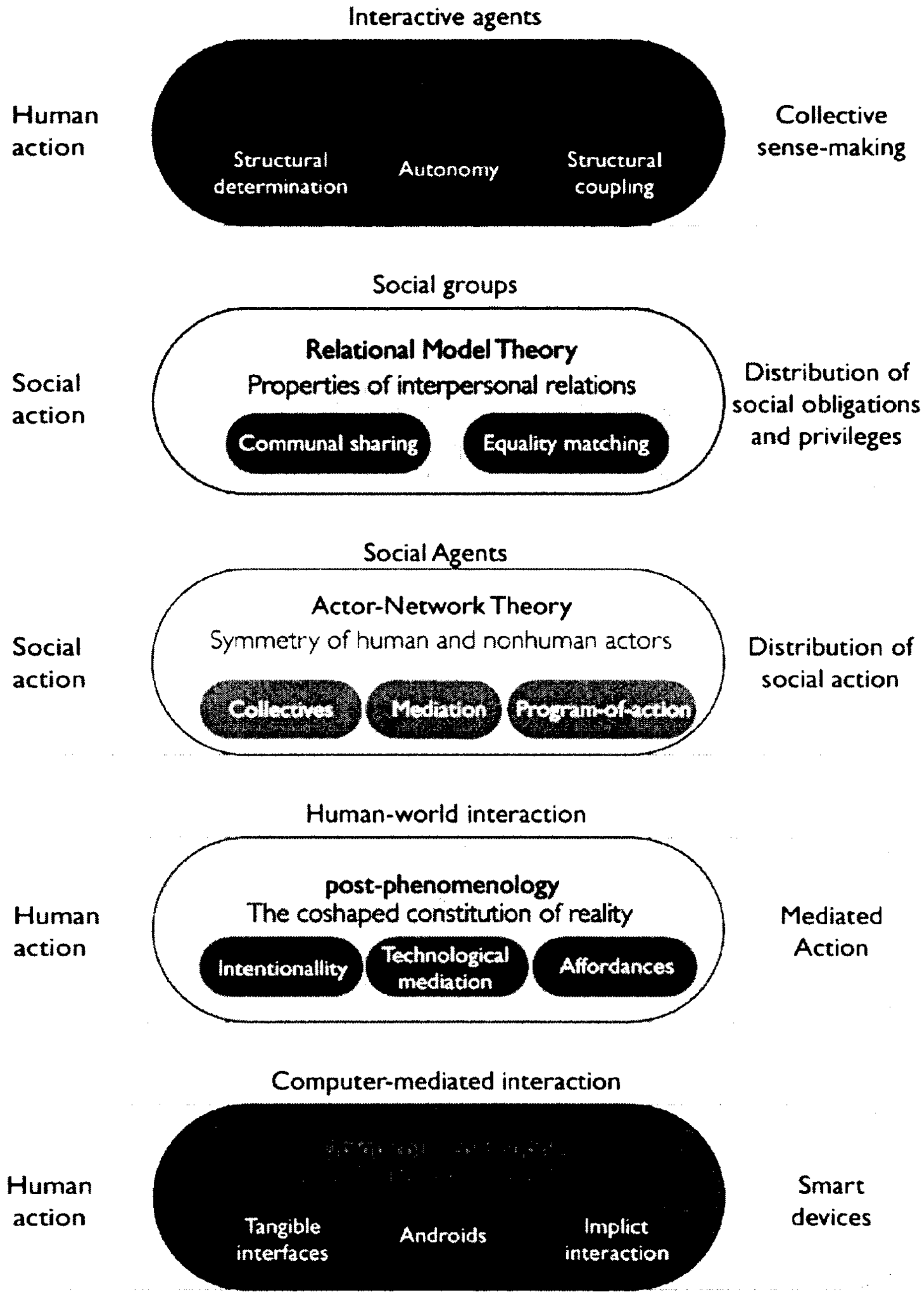

Figure 2.1 Theoretical fields reviewed in this research

2.1 The interaction of collectives

2.1.1 The enactive approach of cognition and agency. In the afterword of the *Tree of Knowledge* (Maturana & Varela, 1992), Varela presents a retrospective of the sustained impact that the book's main ideas have had in a diverse variety of intellectual communities. Some years after its first publication in 1987, Varela proposed the use of the term *enactive cognition* to designate his vision of cognition, extended later in *The Embodied Mind* (Varela, Thompson, & Rosch, 1991).

Although *enactivism* was originally elaborated upon as an explanatory concept of the biological rules of understanding, it has become a solid reference to explain meaningful actions enacted by individuals in the artificial intelligence, and social sciences field. Its applicability relies on the assumption that the world is not given *a priory* but is brought forth as the cognitive unit enacts it. Hence, it contradicts classical views of either cognitivism and connectionism that assume that cognition is an internal process confined to the individual's representational capacities. The two pillars of the enactive proposal are: "(1) the need for a nonrepresentationist view of knowledge based on the sense-making capacity of an autonomous living system and (2) the need to close the circle between what is valid as a mechanism for animals and machines and what pertains to our own experience" (Maturana & Varela, 1992, p. 254). Researchers of *enactive cognition* hold that a unit – either an artifact or a biological individual, instead of elaborating an internal representation of a pre-structured world, makes sense of the world by adapting itself to the exterior disturbances. Such adaptation is not governed by the world's disturbances but by the unit's own bodily structure.

The extrapolation of *enactivism* in behavioral science, artificial intelligence, and design is feasible because of two fundamental ideas: the decoupling of cognitive acts from brain processes, and the explanation of social cognition as an emerging phenomena from aggregated individuals (Torrance, 2005). Reframing cognition as the outcome of simple 'brainless' units capable of sense-making brings out an inspirational starting point for research agendas on non-living systems such as computational agents, robotics and artificial life. Moreover, living organisms with simple nervous systems like ants, exhibit a social behavior derived from the ontogenetic[2] mutual involvement through reciprocal structural coupling among themselves and the environment. The patterns of such social behavior are stable over generations, giving rise to forms of cultural behavior (Maturana & Varela, 1992) highly developed by humans.

In this research, *enactivism* constitutes one of the pillars for the design of smart artifacts because it provides the appropriate framework for the definition of autonomous agents capable of sense-making in their interactive domain as well as principles for the study of agents' action in society. The principles discussed below are: structural determination of systems, autopoiesis and autonomy, structural coupling, adaptivity and sense-making, and embodiment and experience.

A system is **structurally determined** when its constitution and all of its reactions to external phenomena at any instant are determined by its structure. Every structurally determined system has an *organization* and a *structure* as features that characterize how its components and their relations are articulated.

In discussing the definition of organization and structure Maturana says that he

> [...] shall consistently use the word organization to connote the configuration of relations between components that define the class identity of a composite unity or system as a totality or singular entity. I shall consistently use the word structure to refer to the components and the relations between them that realize a system or composite entity as a particular case of a particular class. The organization of a system is only an aspect of the relations included in the structure of the system,

[2] Ontogeny is the history of structural change in a unity without loss of organization in that unity.

> and does not exist independently of the structure in which it is realized. In these circumstances, a system conserves its class identity, and stays the same while its structure changes, only as long as its organization is conserved through those structural changes" (Maturana, 2002, p. 16).

As an example, every triangle has the same organization which is defined as any geometric closed shape with three sides and three angles that always add up to 180 degrees. However, there are triangles of different types such as isosceles, equilateral, acute and others whose structures vary according to the length of the sides and the angles described by them. If an isosceles triangle is transformed into an equilateral one, it suffers changes in its structure but not in its organization, hence it preserves its identity as a member of the triangle class.

The preservation of organization is a condition *sine qua non* for the ontological persistence of the system. That is to say that any change in the organization breaks down the system's integrity and therefore it derives into something different instead. Therefore, the unit's organization identifies it as an instance of its class. However, the system's structure is open to change in two ways: change of state, and change of disintegration. The former makes reference to any change in the system that preserves the organization, the latter to changes that modify the system's organization.

Autopoiesis means literally self-producing. An autopoietic system is a closed set of networked component-producing processes that interact with each other, generating the same generative networked processes. In addition, such a network of processes constitutes the operational boundaries that identify the system as a unit in the space in which it exists (Beer, 2004; Maturana, 2002).

A system has an autopoietic organization when it produces itself. Both artificial and living systems can be autopoietic. "What is distinctive about them, however, is that their organization is such that their only product is themselves, with no separation between producer and product" (Maturana & Varela, 1992, pp. 48-49).

In some instances the word *autopoiesis* is reserved to designate self-producing processes in living systems. Instead, the word *autonomy* is used for autopoietic processes exhibited by a designed unit[3] in either its self-preservation or its engagement with the environment. An artifact, for instance, is considered autonomous if under external or internal perturbations it can regenerate its own constitution to a some level of identity, i.e., a device is autonomous if it can regulate its own structure in order to preserve its organization. Furthermore, autonomous regulated interaction with the environment means that the unit acts asymmetrically in order to regulate the conditions of its exchange with the environment.

To be clear, the system's *identity* is constituted when its processes are operationally closed. *Operational closure* does not mean that the unit self-generates all the matter and energy necessary for its operation. Rather, it specifies that the conditions for a process *P* are provided by other processes, some of which are in turn dependent upon the outcome of *P* (Di Paolo, Rohde, & De Jaegher, 2010).

Structural coupling is the condition of stable and recursive interactions of two or more systems. In the recurrent interaction, some of the participant systems' autonomy can be either maintained or gradually terminated. If maintained, the structural coupling

[3] The expression "designed unit" is used to indicate that the unit is a man-made artifact.

emerges as the historical consequence of recursive interactions, else the interaction is terminated. It is important to clearly have in mind that a system perceives the perturbations from others as triggers for structural changes, but not as governing commands. This is true for all the participant systems in the coupling. Each autonomous system adapts its structure when structurally coupled with other systems or the environment, displaying a form of action. Actions are elicited by the unit's awareness of the surrounding conditions.

In order to maintain or terminate the system's autonomy that is structurally coupled, the system requires adaptive actions that continue or compensate dynamically its structural changes. Such adaptation must happen before the changes exceed the boundaries within which the system's identity is preserved.

Adaptivity is defined by Di Paolo as

> a system's capacity, in some circumstances, to regulate its states and its relation to the environment with the result that, if the states are sufficiently close to a boundary of viability, 1) tendencies are distinguished and acted upon depending on whether the states will approach or recede from the boundary and, as a consequence, 2) tendencies of the first kind are moved closer to or transformed into tendencies of the second and so future states are prevented from reaching the boundary with an outward velocity (Di Paolo, 2005, p. 437).

Some authors argue that ontogenetic structural coupling brings forth *sense-making*. An organism that regulates its coupling with the environment does so because there is a direction that this process is aiming at: that of the continuity of the self-generated identities that initiate the regulation. "Sense-making is the capacity for a system to enact a world of meaning. This entails that the system is able to interact with the environment in terms of the consequences that its interactions have for the conservation of its identity" (Fuchs & De Jaegher, 2009, p. 447). Thus, meaning is generated by the unit's body and its actions. In other words, meaning emerges from enacting the world.

Embodiment and Experience. Maturana and Varela contend that all knowing depends on the structure of the knower. That is to say that the unit's body determines its ways of knowing, consequently the understanding of the world will always be biased by the corporeal condition of the knower. Enactivism rejects the Cartesian duality of mind and body and contradicts the philosophical traditions that assign the power of the mind to control the body. For the enactivist approach, the body is neither a puppet of a centralized cognitive mechanism nor the vehicle of a distributed network of cognitive organs and limbs. Instead, it is the ultimate source of significance; a whole autonomous unity which constitutes, coordinates and organizes itself.

Although phenomenology and enactivism arrive at similar conclusions concerning human experience and the body, their argumentation is distinctively different. Enactivism has no assumption of intentionality nor an assumption of higher cognitive processes of action. Enactivism argues that cognition departs from the origin of life and the phenomenology of processes and interactions enacted by an autonomous unit. Experience and action are inherent to life because to live itself constitutes an act only possible through the body. The body is the place and the means for activity, hence it is a condition for life.

2.1.2 Social interaction. The definition of a social system is controversial because it depends on the theoretical tradition from which it is defined. A bottom-up position claims that society emerges from human agents interacting in collectives, whereas a top-down position argues that society is constituted as the result of individuals' actions that have been formatted *a priori* by institutions.

In the context of this research the point of departure for the characterization of social systems is interactionist. The notion of agency is not constrained to human agency, but is extended to artificial agency as well.

2.1.2.1 The enactive position on social interaction. The research about the origins of meaning in social understanding conducted by Di Paolo, Rhode, and De Jaegher has produced significant contributions to enactivism by offering precise definitions of adaptation and interaction (see, e.g., (Di Paolo, *et al.*, 2010)). They claim that an interaction entails the mutual interdependence of the actions of t least two social agents. Such an action is described as a correlation that may happen accidentally or not. In particular, their research is focused on coordination as a form of non-accidental correlation. One relevant conclusion derived from their experiments with evolutionary robotic models is that in the process of achieving coordination a third autonomous entity emerges between the participants' interaction. They define social interaction as " [...] *the regulated coupling between at least two autonomous agents, where the regulation concerns aspects of the coupling itself and constitutes an emergent autonomous organization in the domain of relational dynamics, without destroying in the process the autonomy of the agents involved*" (Di Paolo, *et al.*, 2010, p. 70. Emphasis in original).

2.1.2.2 The biological position on social interaction. Maturana and Varela define social phenomena – that they also name as *third order coupling* – as those phenomena that arise in the spontaneous coupling of organisms with other organisms. Such coupling ranges from simple to particularly complex interactions when either one or all the organisms have nervous systems. The outcome of the coupling is a recursive phenomenon by which social systems are constituted. Moreover, social interaction "generate[s] a particular internal phenomenology, namely, one in which *the individual ontogenies of all the participating organisms occur fundamentally as part of the network of co-ontogenies that they bring about in constituting third-order unities*" (Maturana & Varela, 1992, p. 193. Emphasis in original).

The animal kingdom is particularly social because reproduction and rearing require the coupling of either progenitors among themselves or with their offspring. But not only reproduction is an instance of animal sociality. Hunting and feeding are usually social as in the case of a wolf pack. To mention a well studied case, an ant colony exemplifies a social system that is chemically governed (Wilson, 1971). Chemical traces left by some of its members when the colony is threatened or when the queen is removed guide the behavior of every single ant that, when aggregated, result in a coordinated macro-organism. This macro-organism is an instance of a metaclass, considered a system dependent on its constituting micro-organisms.

Emergence of cultural behavior. Communication is a form of reciprocal interaction in structurally coupled units that is only elicited in the realm of social systems. The coordinated interplay of signaling drives the participants to sense-making processes that potentially end up in learning. Another mechanism of learning in vertebrates in particular is imitation. By imitating what others do, older generations transmit the knowledge to their descendants.

Cultural behavior is defined by Maturana and Varela as "[the] behavioral patterns which have been acquired ontogenetically in the communicative dynamics of a social environment and which have been stable through generations" (Maturana & Varela, 1992, p. 201). A deep review of culture is beyond the scope of this research, however this definition will prove to be extremely useful to articulate concepts like norms and values in the theoretical framework of this research.

2.1.2.3 The interactionist position on social interaction. The interactionist tradition in sociology to which Strauss (1993) and Schutz (1972) belong, claims that *the social* is the outcome of self-governed individuals acting intentionally upon each other. For interactionists the study of action and its actors' intentions is at the center of the constitution of society. Their units of analysis are often defined as dyads or triads of interacting actors.

Action and behavior. Action and behavior are both instances of activities, however they have different temporalities. As Schutz explains, actions have intention presuming a desired future state of affairs whereas behaviors are spontaneous and are reactions to events happening in the present. Schutz suggests that "what distinguishes action from behavior is that *action is the execution of a projected act.* [...] [T]*he meaning of any action is its corresponding projected act*" (Schutz, 1972, p. 61. Emphasis in original). Furthermore, actions are *conscious* in contrast to *unconscious* behavior. In the process of executing an action the actor has a goal, hence every step is driven by the desired state of affairs. Being conscious of the acting process is being aware of the alignment of every single event to the intended acting trajectory. In opposition, the behavior of an actor does not necessarily respond to his/her intended trajectory of action.

An actor is the agent of an action or a behavior – a person, a group, an organization, or other social unit. However, to make a distinction between action and behavior, it is said that the actor *acts* when he/she executes the former, whereas in the latter he/she *reacts.* An *act* is then the result of an executed action.

The use of *to react* in this research is not constrained to behaviors. It is possible to be used to designate the action executed in response to someone else's action (e.g., *his reaction to the complaints was an apology).*

Strauss (1993) holds that the execution of an action has two dimensions: i) *Acting overtly,* which is the dimension observable by other people, and ii) *Acting covertly*, or reflexively, which cannot be observed by others but can be reported by the actor. Typically mental actions are covert actions (e.g., *I have thought of you*). Here we can see the necessity of an external party, the observer, to determine the action's dimension. In a sense, Strauss' dimensions are not only about an individual executing the action. They also imply the participation of that action in the perceived world of others.

Interaction. The definition of *interaction* is also debatable. The point of discussion is whether or not a reaction is necessary in order to constitute an interaction.

For Strauss interaction is "acting, by an individual or collectively, towards others who are not necessarily aware of this action. The others may not be present, may be dead, may be imaginary, or in some way, may be cultural others (heroes, celebrities, models for the actor). If alive, the others may in turn act toward, or respond to, the actions of the first actor" (Strauss, 1993, p. 22).

In his discussion of interactionism, Agre argues that interaction "suggests that two entities are acting reciprocally upon one another; back and forth, continually and symmetrically. Interaction is a metaphor, and not just an abstract description, to the extent that it describes both entities, in this case individuals and environment, as taking *actions*, not just causing effects" (Agre, 1997, p. 53). Agre positions interaction as a third "thing" emerging from the interacting entities' participation. He concludes that interactionism is about the study of this "third thing" as a principal unit of analysis.

These definitions present two fundamental ideas. First, Strauss clarifies the distinction between action and interaction as the latter is oriented towards the other. Therefore, one condition for interaction is other-orientedness. Second, Agre posits interaction as an emergent meaningful entity characterized as a descriptive metaphor of the participants' recursive intertwining.

2.1.3 Elementary forms of sociality. Fiske (1992) claims that people naturally tend to seek, make, sustain, repair, adjust, judge, construct, and sanction social relationships. In the process of doing so, everyone uses the same set of relational models, which can be clustered in four elementary schemata: Communal sharing, Authority ranking, Equality matching and Market pricing. Fiske's research, supported by evidence from different cultures around the world, contends that regardless of the domain of social action or cognition it is possible to distinguish the relevant social operations or relations when people exchange, contribute or distribute things. Under the name Relational Models Theory (Fiske, 2004) this theoretical framework describes how people regard interpersonal interactions, and how these operations give shape to the primary standards of social morality.

Individuals within a society use the schemata identified by Fiske to organize labor and endow artifacts, land, and time with social significance. Their moral judgments and ideological positions fall within one of the following structures:

- *Communal sharing* is a form of sociality in which the members of a group treat each other as equals, focusing on commonalities and disregarding distinctive identities. The natural attitude of the members of these groups is altruism and kindness. Kinship ties are usually present. A group of the same nationality in a foreign land and a religious group are instances of this form of sociality;

- *Authority ranking* relationships are based on a model of asymmetry among people who are hierarchically ordered. The position of each individual in the ranking entails levels of prestige, prerogatives and privileges, always benefiting those who are at top of the ranking scale. Military and family structures are governed by such a model;

- *Equality matching* relationships are based on a model of even balance and one-for-one correspondence. For example, the underlying morality would dictate that when distributing a pool of resources each person should be entitled to an equal share, and that the direction and magnitude of any imbalance would be meaningful. Reciprocal favors, car-pooling, and tit-for-tat retaliation are examples of this model.

- *Market pricing* relationships are based on a model of proportionality in which all the relevant qualitative and quantitative features of the relationship are reduced to a single value or utility metric that allows universal comparison. The morality of this model is based on rational calculations of efficiency or utility. Of course the archetypical example of this model is the market in which money is the absolute metric. Only Communal sharing and Equality matching are central to this research.

These four models are not intended to be regarded as mutually exclusive. Fiske contends that people belong to several social groups that are governed by one of these four schemata. The reality of social life is a combination of them, and as people get enrolled in institutions or social structures, they interact predominantly under the logic of one of these models or a nested combination of them. It is only for simplicity and clarity that Fiske describes them as if each one was an isolated type.

Fiske's model builds on a more granular formalization of social interactions that provides many useful definitions of properties and relations. By studying people's perception of abstract mathematical properties, De Soto and Kuethe developed a formal model of describing interpersonal relations (De Soto & Kuethe, 1958). De Soto and Kuethe characterized interpersonal relations as binary relations between two people a and b. If a and b are in relation R, the relation is written as aRb. Conversely, the statement that a is not in relation to b is written as $aR'b$. The properties of binary relations R are described in Table 1. The set of all people, referred to as A, can be characterized by the properties of its interpersonal relations.

Table 2.1 Properties of binary interpersonal relations

Property	Complement
Transitive: If aRb and bRc, then aRc	Intransitive: If aRb and bRc, then aR'c
Symmetric: If aRb then bRa	Asymmetric: If aRb then bR'a
Reflexive: For all a in A, aRa	Irreflexive: For all a in A, aR'a
Universal: For all a,b in A, aRb	Absurd: For all a,b in A, aR'b

De Soto and Kuethe identified the following types of interpersonal relations based on combinations of the mathematical properties of binary relations: i) If *R* is transitive and reflexive, it is a **weak ordering of *A***. This is to say that *a* is at least as good as or better than *b* or than *c* - however, it says nothing about the relative distances between them; ii) If *R*, in addition to being transitive and reflexive, is asymmetric, then *R* becomes a **partial or complete ordering of *A***. This new combination of properties entails that if *a* is better than *b* and *b* is better than *c*, then *a* is better than *c*, excluding the reverse possibility, i.e., *c* better than *a*, however d may have an undefined relationship to all three; iii) On the contrary, if *R* is transitive, reflexive and symmetric, then *R* is an **equivalence relation in *A***. This is to say that for the relations in question, *a* is in the same social set as *b*.

Based in part on the work of De Soto and Kuethe, Fiske formalized the underlying set of properties that describes the interpersonal relations of the members of a social group. In his Relational Models Theory he argues that:

Communal sharing is formally defined as an equivalence relation of *A* because people are socially equivalent and are each entitled to the same obligations and privileges;

Authority ranking is formally characterized by an ordering of *A* because obligations and privileges are unevenly distributed across the ranked members of the group;

Equality matching is also an ordering of *A*, but in addition such a model has the same properties as the Abelian group: additive identity (zero value), additive inverse (subtraction), associative law, and commutative law. In the case of distributing resources among people in Equality matching groups, they prefer to have as much as their partners (or more, in that individuals' selfishness may override their social beliefs) because equality is expected and enforced. A sense of reciprocity has strong value and free riders are regarded as morally questionable; and

Market pricing has all the properties of Equality matching plus some others. Its structure corresponds to an Archimedean ordered field, which characterizes people's assets as an ordered set of integers or fractions. People interacting in Market pricing groups are typically found in trading activities, and their interactions are assessed in ratios that they expect to maximize.

Fiske defines the residual cases not characterized by any of the above models as either *asocial* interactions or *null* interactions. Asocial interactions are those in which people regard others as instruments to achieve some ulterior end. Null interactions are those in which people ignore each other's goals, presence or conceptions.

A closer look at Fiske's definitions of Communal sharing and Equality matching helps to understand the role of communal pools of resources in the interactions at interest in this research.

2.1.3.1 Communal Sharing. It is a form of sociality in which every member of a social group is entitled to at least the same privileges as the others. Members are expected to contribute as much as they can, and each person is obligated to share with other members who need resources or ask for help. In this kind of social group people treat material artifacts as held in common, as pools of communal things to be used as needed. Communal sharing groups are based on a sense of belonging that comes from kinship ties or from the identification of common attributes. This common identity elicits altruism, contribution, and kindness among the members of the group. In such a form of sociality there is no hierarchy within the group, individuals are regarded as homologous and the important expression of identity is one's expression of affiliation to the group.

Fiske (1992) argues that commons – historically, communal grasslands, but also any shared pool of resources – are the most important manifestation of this relational model because the sense of property is shared among group members who feel that they can use it freely. In a common, any available field can be used by anyone, and no one is obligated to pay or compensate for its use. Communal things are symbols that represent the group as a whole - land becomes associated with the identity of a family who works it over generations, or with the house they inherit from their ancestors. "[R]elics, heirlooms, keepsakes, and wedding rings" (Fiske, 1992, p. 693) are also instances of such symbols.

A decision-making process in Communal sharing groups seeks for consensus and joint judgment. Even though individuals have personal positions, they consider the joint decision in terms of collective benefit rather than individual benefit. Such group rationale creates uniformity of expression among the members due to the tendency to correspond to the reference group.

Members of Communal sharing groups tend to merge themselves into a whole that they regard as larger than the union of the constituent parts. For example, shared citizenship may bond a set of people who as a group represent a whole country or region. On a much smaller scale, couples in romantic love are merged into a unit that is not considered by them as the simple addition of their two selves but as a larger social entity. The underlying shared value in Communal sharing can be expressed, "if we belong together, my needs and your needs are the same thing. The essence of this ethical or jural standard is one of mutual compassion and mutual responsibility: Never send to know for whom the bell tolls, it tolls for thee." (Fiske, 1992, p. 698). A sense of solidarity is elicited when one of the members of the group is threatened or attacked by an outsider. In that case, the offense is regarded as victimizing the whole group and receives a strong response from the group as a whole.

One issue derived from Communal sharing logic is the problem of the sustainability of communal resources. If everyone in the group is entitled to use the same limited pool of resources, then, there is a maximum number of members the group can afford. The problem is depicted in the *tragedy of the commons*:

> Picture a pasture open to all. It is to be expected that each herdsman will try to keep as many cattle as possible on the commons. Such an arrangement may work

> reasonably satisfactorily for centuries because tribal wars, poaching, and disease keep the numbers of both man and beast well below the carrying capacity of the land. Finally, however, comes the day of reckoning, that is, the day when the long-desired goal of social stability becomes a reality. At this point, the inherent logic of the commons remorselessly generates tragedy (Hardin, 1968, p. 1244).

More formally, a group using a pool of resources is a sustainable system if it maintains at least a critical mass of resources needed for its regeneration. There is an equilibrium point in which a group of individuals uses resources from the pool, and at the same time allows the pool to regenerate. If the population grows beyond that equilibrium there are only two possible scenarios: 1) The population keeps on growing, heading inevitably to its extinction due to the depletion of resources, even though each individual reduces his/her consumption of resources aiming to restore the system's equilibrium; 2) There is a social agreement to stop the expansion of the population. Epstein and Axtell (1996) define the system's population capacity as its *carrying capacity*. Hardin (1968) argues that there is no technical solution to the problem of scenario 1, and that scenario 2 requires a dramatic change in the moral stance of the group to solve it: strict self-control of population.

In the tragedy of the commons, selfish action leads to utility with positive and negative components. If a herdsman increases his cattle in 1, his positive utility is +1, but at the same time the additional overgrazing created by that additional cow yields a negative utility of a fraction of -1. He is the only one who gets the benefit of the positive utility, whereas the whole group receives the negative impact of overgrazing. The attitude of the group towards the one who introduced that additional cow depends of the current situation of resources. If in scarcity, the group will strongly oppose that member, whereas in abundance it may be more flexible. Fletcher argues that "the morality of an act is a function of the state of the system at the time it is performed" (Fletcher cited by Hardin, 1968).

2.1.3.2 Equality matching. It is a form of sociality in which every member of a social group is entitled to the same privileges and obligations without distinctions of identity. It is one of the fundamental models underlying many moral and law systems across different cultures. Its core principle argues for egalitarian exchange between parties who expect balanced reciprocity to their actions. If in a dyad, one expects reciprocity from the other party. If in a larger group, the reciprocity comes from the other members regarded as a unit.

Reciprocal action in Equality matching groups is balanced if the action equals the one being reciprocated. If someone is invited for dinner at a friend's home, the guest should reciprocate the invitation with a similar invitation. In Equality matching groups, the value of each interaction is assessed not in scales or ratios but simply by counting the number of interactions between the parties. The desired equilibrium is a zero difference between them. For instance, if John invites Steve for dinner twice, then Steve owes John two dinner invitations equivalent to the meals offered by John. Steve equally matches John at the moment John accepts Steve's second invitation. Even if Steve offers John a single dinner that costs two or three times more than the ones offered by John, Steve would still owe John one invitation. What matters is not the monetary value of the social interaction but the social gesture of the second invitation. Ariely (2008) argues that social interactions have social and market norms and that these logics may conflict. As an example, giving a gift is highly appreciated from a social perspective, but it is a waste of resources from a market perspective. Where social norms are stronger than market norms, other phenomena like altruism and solidarity prevail.

The instantiation of what is exchanged or contributed in Equality matching interactions varies from immaterial to material things. For example, people have a clear sense of how much is needed to balance the load when their peers' propositions don't pull their weight; legislators reciprocate votes in favor of their peer's propositions; people engage in carpooling, trade baby or pet sitting; and urban neighbors clear snow out of each others' front sidewalks.

People in Equality matching groups do not feel emotional discomfort when their share is equal or greater than the average, but they think that a slightly-less-than-equal share is barely acceptable. In a reference group, as in the ultimatum game (Thaler, 1988), one expects to do as well as the other members but never less well than them.

Fiske argues that "[s]omething is called a *norm* when it is viewed as an external constraint coming from society, and it is called a *motive* when it is perceived as emanating from within the individual. The same directive force is called a *moral principle* when it is regarded as a universal obligation" (Fiske, 1992, p. 704). Equality matching is a moral principle when it is regarded as a binding principle which supersedes individual motivations. It is a motive when, in the case of an imbalance, a partaker deliberately takes actions to restore the stability of the group more than others. And finally it is a norm when partakers mutually demand matching behaviors.

Despite the tendency of Equality matching relations to seek an equilibrium, there are cases where they may remain imbalanced, and they may even break up if the unbalance is never repaired. For example, Equality matching relations may end up in Authority ranking relations if recipients don't repay their "debts" in kind, and instead persistently pay back with respect, loyalty, deference or submission.

2.2 Meaning in social interaction

2.2.1 Domains of meaning. So far, we have discussed action as discrete units identifiable in our stream of consciousness. Indeed, talking about actions in everyday life is a common cognitive operation that seems natural and spontaneous. Nevertheless, to render discrete units of action is a high level cognitive process that is hard to define in concrete models. One approach is the study of *speech acts* that correspond to the analysis of action through its verbalized representation (Searle, 1995). Other approaches, more suitable for this research, are based on actors' embodiment, their indexicality and temporality.

2.2.1.1 Interactionist meaning-context. Schutz' study of action and meaning considers how to determine when an experience starts and ends in the continuous stream of experiences. His analysis contends that the reflection about one's own experience constitutes it in an act itself. So the reflection about different moments of one's experience gives as a result a series of chronological acts. If those acts have relational attributes that contribute to the constitution of a monothetic[4] object (Hjørland, 2006), i.e., an action, they all belong to the same *meaning-context.*

[4] A monothetic class is defined in terms of characteristics that are both necessary and sufficient in order to identify members of that class. This way of defining a class is also termed the Aristotelian definition of a class.

In Schutz' words:

> Let us define meaning-context formally: We say that our lived experiences E_1, E_2,..E_n stand in a meaning-context if and only if, once they have been lived through in separate steps, they are then constituted into a synthesis of a higher order, becoming thereby unified objects of monothetic attention (Schutz, 1972, p. 75).

As an example, the monothetic object *smoking a cigarette* is constituted by discrete acts such as putting the cigarette in the mouth, lighting a lighter, lighting the cigarette, extinguishing the lighter, smoking the cigarette and extinguishing the cigarette. Any act of one's own experience of smoking that shares the characteristics of *smoking a cigarette* arc-of-action belongs to the same meaning-context.

From the concept of meaning-context, it is possible to infer that the basic characteristics for an act to be considered part of a same monothetic object are its indexicality (space), contemporaneity (time), and course of action. The course of an action is the set of actions and interactions that have contributed to the evolution of a phenomenon.

A polythetic class is defined in terms of a broad set of criteria that are neither necessary nor sufficient. Each member of the category must possess a certain minimal number of defining characteristics, but none of the features has to be found in each member of the category. This way of defining classes is associated with Wittgenstein's concept of "family resemblances." From: Monothetic/Polythetic classification. URL: http://www.iva.dk/bh/lifeboat_ko/CONCEPTS/monothetic.htm. Retrieved June 25, 2010.

An $action_A = act_{a1} \cup act_{a2} \cup \ldots act_{an}$

which is equivalent to

$action_A = meaning\text{-}context_A$.

The $action_A$ is a *monothetic object*.

A chronologically structured set of actions is an experience. Therefore,

$experience_X = action_{XA} \cup action_{XB} \cup \ldots action_{XN}$.

Thus, the $experience_X$ is a *polythetic object.*

Figure 2.2 Meaning-context and experience as monothetic and polythetic objects

Furthermore, Schutz contends that the experience of an artifact "is constituted out of appearances as we encounter [it] in our stream of consciousness. Such appearances hang together in a context of meaning. As they follow one another in regular sequence, our experience of the [artifact] is built up" (Schutz, 1972, p. 79). Therefore, a scheme of our experience is a meaning-context constituted out of a sequence of actions bracketed as a unit with temporal dimension. Meaning is attributed to actions as they are added to the context by making reference to past experiences – the stock of experience. Figure 2.2 presents a formal definition of meaning-context.

Intersubjectivity and action types of meaning. Schutz presents two fundamental ideas in order to understand how *the social* is constituted (Schutz, 1972, pp. 25-33): i) the other is like me, and ii) the world is given equally to all of us, thus we experience the same here and now.

These ideas entail that the world's meaning is the result of my experience of it and that social meaning is constituted as an inter-subjective phenomenon.

In order to explain the constitution of social meaning Schutz makes a distinction between objective and subjective meaning. The basic idea is that an action performed by an actor has an attributed meaning by its actor that might be different than the one inferred by an observer of the same action. It is plausible that the same action could have as many meanings as observers. Therefore there are two types of meanings, the one attributed by the actor, deemed *subjective*, and the many others inferred by the observers, deemed *objective*. Surprisingly, the objective and subjective meanings often converge in the same interpretations. As an example, Schutz proposes the case of 2 x 2 = 4, a linguistic expression, or Beethoven's Ninth Symphony. These are examples of meaningful expressions in themselves. "Here the term 'objective meaning' signifies a unit of meaning considered as an ideal object" (Schutz, 1972, p. 33).

Motives for action. The motives for action have two possible connotations. On the one hand, i) the *In-order-to* connotation makes reference to the desired state of affairs that someone has fantasized about his/her own involvement. In order to achieve such a state, a sequence of actions has to be carried out. Every action performed in the direction of the desired goal constitutes part of the same meaning-context. It is grammatically correct to build expressions with *because-of* that are equivalent to *in-order-to*. As an example it is possible to say, *In order to kill the headache I am taking this pill*, which is equivalent to *because of the headache I am taking this pill*. Schultz calls this a *pseudo because-of.*

On the other hand, ii) the *genuine because-of* motivation, refers to an action enacted due to a situation that happened in the past. Because of *X* I do *Y*. *X* is necessary to give meaning to action *Y*, otherwise my experience performing *Y* would be a simple behavior. An example could be: *because of the rain I am using the umbrella*.

To inquire about the *in-order-to* motive points towards the understanding of the consequences of action, whereas inquiring for the *genuine because-of* is asking about the antecedents of that action.

2.2.1.2 Social domains in the enactive approach. The enactive approach to cognition has a reputation of being grounded in lower-level sensory motor cognition, but it is said to be hardly extendable to truly human social interaction. Steiner and Stewart (2009) contend that researchers of enactive cognition naively regard a social phenomenon as any dyadic interaction between two individuals, or the aggregation of them in multi-agent systems. They claim that in order for the enactive approach to become a rounded theoretical framework extendable to human social cognition it is necessary to develop an approach for higher-level cognition which contemplates a more robust concept of society.

Steiner and Stewart argue that the enactive definition of social interaction does not provide a complete account for human society. They claim that social domains are constituted by structural norms that persist, even though the interactions enacted within those domains cease, or some of the interacting participants come to an end. It is only in the context of such domains that dyads or any other kind of social units can be properly social. Therefore a social phenomenon cannot be characterized merely by the number of participants – provided that there are at least two, but also by the social domain within which their interaction unfolds.

This raises two fundamental questions: i) What should we understand as social domain? and ii) If an autopoietic system is an operationally closed and autonomous process, how can it be influenced by the social domain within which it interacts?

What is a social domain? Steiner and Stewart assert that the characterization of the social has oscillated between the properties of interrelated individuals, and the properties of a domain that contains and shapes inter-individual relations. In other words, there is no dominant answer to the question about the constitution of society.

On the one hand, the interactionist line of thought claims that social domains are the outcome of individuals' intentional acts displaying cognitive processes (coordination, imitation, cooperation) observable in either coupled agents or the collectives constituted by them. For instance, Schutz' phenomenological thesis of society argues that the foundation of the social relies on the shared meaning of agents' actions among the members of the community to which they belong. On the other hand, social scientist like Durkheim and Parsons explain the social as a phenomenon that cannot be attributed to single individuals but rather to larger institutions that articulate social facts through structural norms such as traditions, religion, politics, education and so on.

Steiner and Stewart feature Giddens' approach as a third position that attempts to overcomes the above dilemma. Giddens (1984) argues that no primacy should be attributed either to the individuals nor the institutions. Instead, they co-exist and are co-constituted. Such a conciliating position recognizes the individual's agency and the structural property of institutions. It acknowledges the micro-social interaction as the locus of social reproduction, yet asserting that every interaction is loaded with the imprint of the macro-society. "Every act which contributes to the reproduction of a structure[5] is therefore an act of production as it *may* initiate change by altering that structure at the same time it reproduces it" (Giddens 1976, p.128 cited by Steiner & Stewart, 2009, p. 533. Emphasis in original).

This conciliating viewpoint offers a promising road for the elaboration of the enactive approach in social sciences, as Steiner and Stewart explore further. The "social life is enacted in inter-individual interactions, more precisely in the constructive dialectics at work between interpersonal engagements and extra-personal structures" (Steiner & Stewart, 2009, p. 534). The structures – institutions – in question are impersonal and evolve over time. Furthermore, such structures stage norms, principles, patterns, habits, modes, frames among other aspects of society. All these kinds of norms work together constituting the social medium in which inter-individual culturally molded interactions become truly social. Although Steiner and Stewart do not include the concept of culture in their argumentation, it is possible to infer that there is a connection between the evolution of the above structures and the formation of cultural behavior as defined by Maturana and Varela. Thus, as social structures evolve over time, cultural behavior accumulates over generations.

[5] Institutions and structures are used conversely by Steiner and Stewart.Steiner, P., & Stewart, J. (2009). From autonomy to heteronomy (and back): The enaction of social life. *Phenomenology and the Cognitive Sciences, 8*(4), 527-550.

As a conclusion, a social domain is defined as the set of social structures present at the moment when agent's interaction chains unfold. It is dynamically generated by agents' interactions which, in turn, affect such structures by reinforcing or molding them.

Autonomous units in social domains. Is an autonomous agent really autonomous if it operates within a structured social domain? In what extent the social structures constraint autonomy?

One of the signature features of an autopoietic agent is its *operational closure*. It is defined as the agent's preservation of its own processes, which are aimed to maintain or improve its own integrity, yet interacting with the environment or other agent. Maturana and Varela claim that interactions between agents and environments or other agents are not inconvenient or undesirable but, on the contrary, necessary and unavoidable, driving to structural coupling between the interacting parties. This is why recursive coupling with the environment or other agents leads to structural changes within the autopoietic agent, producing a homeostatic coupling. Therefore, the agent's operational closure does not isolate itself but, on the contrary, makes it highly dependant on the environment and other agents.

The success of the agent's structural coupling is highly reliant on how it abides by the social domain's norms and social structures. The higher the alignment of the agent's action to the social structures, the higher its structural coupling with the members of that specific social domain. Steiner and Stewart define the effect of social structures on agent's action as heteronomy (Steiner & Stewart, 2009) because they argue that social structures are external principles to the agents that govern its action and are largely independent of the agents in question.

According to Maturana and Varela, agents and environments are structurally coupled when the result of their interactions is the preservation of the agent's identity, i.e., their own organization and structure. In that vein, heteronomy fits in the enactive argumentation if it is understood as the cultural medium where the unit encounters resources and constraints that enable its social action. Within such a cultural medium autonomous agents mingle with other agents, sharing the same historically constituted social platform.

2.2.2 Participatory sense-making. The enactive approach to social cognition entails a robust framework for the explanation of distributed sense-making among participants in an interaction process. Such processes could be explicitly motivated or emerge serendipitously from the execution of the participants' independent plans and goals.

Participatory sense-making is the result of social encounters that shape participants' understanding. Such encounters draw forth meanings only discernable in social interaction. Participatory sense-making is characterized in the interaction of autonomous agents, emerging as an autonomous domain in itself. In the context of that interaction, participants' actions give shape to each other's cognition in a sense-making process that emerges only in the actualization of mutually other-oriented interaction.

The units of analysis for De Jaegher and Di Paolo (2007) are face-to-face encounters in everyday life. These are instances of what social scientists call the micro-level of social analysis. Hence the macro-level analysis – which aims to explain how the society forms, evolves, and is transformed – is not covered in their studies. Their research strongly influences this research because, although this research is interested in social networks instead of dyads of interacting agents, their conclusions are extendable to any autonomous agent, and make a clear point concerning distributed sense-making in a group of participants.

The relevance of participatory sense-making is that the interaction process can exhibit autonomy. As a proof of concept, they observed people walking in opposite directions in a narrow corridor. Fuchs and De Jaegher's interest was to study the emergence of interaction and its influence in its members. Albeit the participants were not supposed to interact because the corridor was wide enough for them to pass without disturbing the other, some people entered unexpectedly into trajectory negotiations. As a result, the parties struggled to coordinate and maintain their intentions, until they finally fulfilled their goals. Their conclusion was that "an interaction process, in becoming autonomous, can override the intentions of the individuals involved in it" (Fuchs & De Jaegher, 2009, p. 449).

Fuchs and De Jaegher (2009) observed that social cognition is wrongly assumed as a capacity confined to individual reasoning. Instead, sense-making activities, such as interpersonal coordination of movements or utterances, happen 'in-between' people. The spectrum of interpersonal meaning-making opens up domains of sense-making ranging from low level cognitive mechanisms (e.g., pointing with a finger), to cognitive processes of higher order (e.g., having a conversation). They argue that the interaction process is characterized by its autonomy established in the co-regulation of the process by the two agents, yet maintaining their own autonomy during the process. Such interplay is interpreted in this research as two levels of autonomy: that of the interaction process as such, and that of the individuals engaged in interactions. The latter is named *extended collective autonomy*.

2.2.2.1 Implications of enactive cognition and participatory sense-making in this research. The anticipated implications of participatory sense-making in the definition of social interaction, agent constitution and meaning-context are below.

- Interaction regulation unfolds in the process: In the case of an unintentional interaction, individuals do not fully control it. What regulates the coupling is the coordination process itself, or rather, the mutual reinforcement of interaction and coordination.

- New meanings can emerge in the interaction: The breakdown of a coordinated pattern of interaction can evoke new significance of the participants' own actions, each other's interactions, and the environment.

- Actions can only be completed in the interaction: Interactions are usually beyond the scope of individual action (e.g., the act of giving can only be completed in a social interaction).

- The change of one agent's perspective may influence other agents identity in the network.

2.3 Sociality with artifacts

In this section, a sociological framework suitable for the understanding of the role of artifacts in society is introduced.

2.3.1 What notion of artifact? The two notions of artifact traditionally used in social sciences are *commodities* and *instruments*. On the one hand, *commodities* tend to be defined in a logic of value and exchange. In the sense of value, artifacts are symbols operating within a cultural system of signs, conveying meaning and status as the articulation of connotations and denotations via the form of artifacts (Baudrillard, 1996). In the sense of exchange, they are manufactured goods associated with the labor spent in their production. Either as symbols or as goods they are characterized as objects of desire (Forty, 1986). On the other hand, *instruments* are defined as tools or equipment serving to accomplish a practical purpose. They are the necessary means to cope with the world, hence, their logic is fundamentally instrumental.

Knorr-Cetina offers *knowledge objects* as an alternative notion of object based on Rheinberger's study of expert communities. As researchers in the lab, people socialize around things they want to understand and explain. Those things are defined as incomplete and continuously unfolding units positioned at the center of the society's structure. In Knorr-Cetina's words, objects of knowledge are "characteristically open, question-generating and complex. […] [They] seem to have the capacity to unfold indefinitely. […] [T]hey continually acquire new properties and change the ones they have" (Knorr-Cetina, 1997, p. 12).

Knorr-Cetina theorizes knowledge objects as a dynamic structure that can never be attained. Therefore, on the subject side "this lack corresponds to a structure of wanting, a continually renewed interest in knowing that appears to be never fulfilled by final knowledge" (Knorr-Cetina, 1997, p. 13). In other words, the subject is constantly trying to satisfy his/her desire of knowing more about such an object.

I contend that the dynamics of objects of knowledge exhibit self-autonomy or extended autonomy. As viruses in the lab, their dynamics are autonomous, whereas, in the case of the market shares, their price variability exhibits an extended autonomy from their traders' activity in the stock market. For the traders and owners of shares, market shares are objects of knowledge, which are constantly unfolding, opening, question-generating and exhibiting complexity.

This research envisions material instantiations of knowledge objects as artifacts that continually mutate into something else while preserving their organization. They are translated into all manner of signs. In that sense, they can be instantiated as signifying artifacts, material things that evolve, mutate, and transform preserving their condition as objects of inquiry.

2.3.1.1 Actor-Network Theory (ANT). ANT is a sociological theory mainly developed by Latour (1996,1999,2005; Latour (Jim Johnson),1988), Callon and Law (1995), contending that society is constituted by networked symmetrical humans and nonhumans actors. "To be symmetric, for us, simply means *not* to impose *a priori* some spurious *asymmetry* among human intentional action and a material world of causal relations" (Latour, 2005, p. 76). Moreover, one of the fundamental claims of ANT is endowment of the capacity of action in society endowed to both human and nonhumans. Anything that modifies the state of affairs by making a difference is an actor. The way nonhumans act is not to be intended as causal action. ANT does not claim that artifacts do things instead of humans. The meaning of nonhuman action is revealed as artifacts "allow, afford, encourage, permit, suggest, influence, block, render possible, forbid" states of affairs (Latour, 2005, p. 72). Although nonhuman agency seems contradictory, it is brought forth in the analysis of courses of action affected by the participation of artifacts in *collectives* constituted by them and humans (Callon & Law, 1995). From this perspective, *the social* occurs in the interaction between actors characterized as intermediaries or mediators. Intermediaries are agents in the network that channel or articulate actions with no transformation of the collective's program-of-action, whereas mediators are agents that may cause the modification of others' programs-of-action by transforming or *translating* their interests.

In Science Technology Studies (STS), ANT is positioned in between the opposing theories of technological determinism and social construction of technology (Fleischmann, 2006). On the one hand, technological determinism attempts to explain the interaction between technology and society as a one-way causal relationship; thus society is transformed by inevitable and predetermined force of technological change. On the other hand, social construction of technology portrays society and culture as ultimately responsible for the new technologies and how they shape society. Actor-Network Theory can be positioned in between these theories because, as Latour argues, technology is not a means for action, but a way where the being is revealed (Latour, 1999). Consequently, the symbiotic and symmetrical relationship between social actors – humans and nonhumans – guarantees their co-existence, and accounts for the social organization and structure.

But how do nonhuman actors act? What might be the action an artifact performs by itself? Are we talking about autonomous agents? ANT does not deal with autonomy and it is not specifically concerned with robotics. What ANT contends is that any actor taking part into a program-of-action performs an action. As an example, smoking could be the program-of-action someone might have. In order to perform it, he/she lights a cigarette using a lighter. The question is: was the cigarette lit by the lighter or by the person? Clearly, the lighter itself cannot light the cigarette, but it is also evident that the smoker could not do it by his/herself either. Hence, both the smoker's and the lighter's programs-of-action are translated[6] into a new collective – smoker-lighter – with its own program-of-action. Furthermore, the network of actors emerges when we trace back other human and nonhuman participants involved in the domain of action such as the tobacco shop owner, the tobacco and the smoking paper.

2.3.1.2 Human and nonhuman actors. ANT rejects *intention* from nonhuman actions. Although *intention* characterizes some instances of action it is not a fundamental predicate for the constitution of agency. Latour holds that the *potentia*-act schema is not applicable in a social theory interested in sharing sociality with things (Latour, 1996) because user-object hierarchical structures are problematic for the framing of distributed action in a network of human and nonhuman actors. By removing *intention* from the list of ingredients for action, the point of origin of action is also withdrawn. What remains is a stream of activity in which it is only possible to identify events of agent mediation without discrete inputs and outputs.

Another consequence of removing intention from agency is the balancing of human and nonhuman actors as symmetrical agencies. Latour offers a famous example:

> "'Guns kill people' is a slogan of those who try to control the unrestricted sales of guns. To which the National Rifle Association replies with another slogan, 'Guns

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[6] The word *translation* is used to keep consistency with ANT terminology. Translation means the creation or modification of a link between two actors that to some degree modifies their original program-of-action.

don't kill people; *people* kill people.' The first slogan is materialist: the gun acts by virtue of *material* components irreducible to the social qualities of the gunman. [...] The NRA, meanwhile, offers a *sociological* version more often associated with the Left: that the gun does nothing in itself or by virtue of its material components. The gun is a tool, a medium, a neutral carrier of human will. If the gunman is a good guy, the gun will be used wisely and will kill only when appropriate. If the gunman is a crook or a lunatic, then, with *no change in the gun itself*, a killing that would in any case occur will be (simply) carried out more efficiently. What does the gun add to the shooting? In the materialist account, *everything:* an innocent citizen becomes a criminal by virtue of the gun in her hand. The gun enables, of course, but also instructs, directs and even pulls the trigger [...] Its object has its script, its potential to take hold of passersby and force them to play roles in its story. By contrast, the sociological version of the NRA renders the gun a *neutral* carrier of will that *adds nothing* to the action, playing the role of a passive conductor, through which good and evil are equally able to flow" (Latour, 1999, p. 176. Emphasis in original).

From the example above, to be a criminal is not an *a priori* class but an emergent condition derived from the transient arrangement of circumstances in the network of actors. Gun-gunman is a collective that describes the association of networked interacting actors. An actor is constituted as a member of a collective when his, her or its program-of-action is articulated with another actor.

2.3.1.3 Programs and anti-programs of action. A program-of-action is a script of what an actant[7] may do. In the case of a human, it is associated with his/her intention and may be instantiated in countless forms. In the case of a nonhuman the program-of-action is predominantly related to its function, however it might have other rerouted programs-of-action as a function of the materials it is made of, its dimensions, or the context where it acts (e.g., the lighter's program-of-action is to light cigarettes, but it can be used to ignite a gas stove or burn a piece of paper).

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[7] To keep consistency with the ANT terminology, the word actant is used as a synonymous of actor. The problem with 'actor' is that it connotes human agency, hence it is inconsistent with ANT's claim of symmetry between human and nonhuman actors.

The constitution of a collective is the result of the association of two or more actants' programs-of-action, from which a third entity arises, this is a collective actor whose program-of-action is the articulation of the program-of-action of the parent actors.

Collectives are prone to dissolve due to anti-programs-of-action, generating a dynamic of emergence and dissolution. An anti-program-of-action impedes the duration of the collective because its persistence is inconvenient for the constituting parties. In the above example, the collective gunman-gun is dissolved because the criminal's fate worsens if he/she is found with the gun in hand. But in the case of a police officer, such collective persists over time, hence constituting an institution.

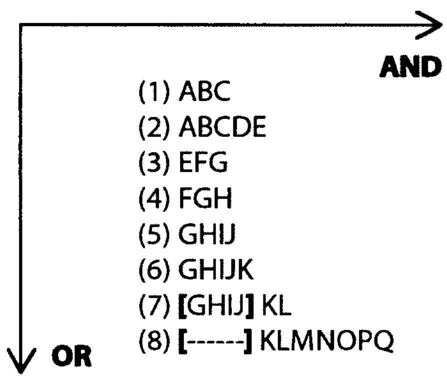


Figure 2.3 Table of associations and substitutions of actants in collectives over time (Latour, 1999)

In the dynamics of society, collectives are continuously being associated and dissolved. Latour describes this as two intersecting dimensions: association or AND dimension, and substitution or OR dimension. The former is about the number and order of the actants associated in the collective; the latter refers to the collectives' variation over time. In Figure 2.3 the horizontal axis corresponds to the AND dimension and the vertical to the OR dimension which also connotes a chronological line. Each one of the letters represents an actant of a given collective. Each row is a collective of actants in a particular moment in time. As time evolves, collectives emerge and dissolve but some of them remain over time constituting institutions. Institutions can be *black-boxed* together and adopt an identity as an aggregated actor.

2.3.1.4 Mediators and Intermediares. All social groups use mediators and intermediaries in their activity. *Mediators* and *intermediaries* are means to produce *the social*. An *intermediary* is what carries meaning or conducts force without modifying it. By defining its input it is possible to yield its output. On the contrary, a *mediator* transforms the input into a *different-in-nature* output. Mediators transform, reduce, distort and modify the meaning or the elements that are being transported.

2.3.1.5 Assembly of meanings of mediation. In order to provide a detailed analysis of technical mediation, Latour identifies four different meanings of mediation which are closely interrelated: translation, composition, reversible black-boxing, and delegation (Latour, 1999). The meanings of mediation are relevant in this research as they account for the possible forms of action enacted by a collective of humans and nonhumans.

- **Translation**. In ANT it means the "displacement, drift, invention, mediation, the creation of a link that did not exist before and that to some degree modifies the original [programs-of-action of the parent actors]" (Latour, 1999, p. 179). The smoker's program-of-action is to light a cigarette. In order to achieve that, he/she can use different instruments like a matchbox, a lighter or a stove. Each one of those nonhuman actors has its own program-of-action; the matchbox and the lighter are prescribed – or designed – to light cigarettes whereas the stove is not.

Let us say that the smoker decides to involve the stove in his/her course of action. Although the stove is not designed to light cigarettes, its program-of-action is translated into a third program-of-action ascribed to the smoker-stove interaction. The result of the interference of actors' programs-of-action is the articulation of new programs-of-action.

- **Composition** is a meaning of mediation in which actants can compose several associations in order to outline new alternative programs-of-action that fit the collective intention. Taking further the cigarette smoker example, let us assume a group of non-smoking friends gathered together in someone's home kitchen. In that context the friends-smoker-stove program-of-action is not viable because smoking in the kitchen would disturb the non-smoking parties. Only the program-of-action patio-smoker-lighter or patio-smoker-match sound reasonable; otherwise the smoker would need to smoke somewhere outdoors or decline his/her intention of smoking. In that strand, actors blend their own programs-of-action into a new one.

- **Black-boxing.** Latour uses the term *black-boxing* to refer to the encapsulation of programs-of-action resulting in concealing the number of actors taking part in the action. Oftentimes the mechanism to unveil the network of associations is to analyze why the program-of-action breaks down. The mailing service serves as an example: the sender leaves a package at the post office assuming a timely delivery. After a reasonable number of days the recipient indicates to the sender that he/she has not received the package. Then the sender would need to visit the post office to track the package and to determine what actor did not perform his/her part correctly – reversing the black-boxed service. This technique would bring to light the set of actors and the network from a black-boxed composition.

- **Delegation** consists in inscribing a program-of-action in an actor. Latour's archetypical example is the speed bump that controls a driver's behavior even though there is no policeman present. In this case, the designer inscribed the policeman's program-of-action of controlling the driving speed into the speed bump. This form of mediation highlights the relevance of a designer's role in the shaping of technological mediated collectives.

2.4 The notion of agency

Selected definitions of agency are introduced in this section. These notions of agency serve as a reference for proposing an adapted definition of agency in Chapter 3.

2.4.1 Sociological agents. Two positions in sociological theory are discussed selectively for their contrasting notions of agency (see Rose, Jones, & Truex, 2005) On the one hand, the notion of *structuration* (Giddens, 1984) represents the traditional position that reserves agency to humans. Artifacts lack any capacity for performing an action independently. On other hand, Actor-Network Theory proposes a symmetry between humans and nonhuman actors. Artifacts thereby do have forms of action that account for the constitution and preservation of social structures. Moreover, for followers of Giddens' structuration theory, artifacts are resources employed by human agents as tools, whereas in Actor-Network Theory humans and artifacts interweave in the form of networks.

2.4.2 Computational agents and social interaction. Two major strands of research regarding computational agency in social interaction are especially germane to this research: the first is influential in design of androids; the latter provides theoretical orientation for Agent-Based Modeling. The first strand points towards fulfilling of the Turing test; the latter points towards the analysis of the structure of social groups. Although both are concerned with social interaction, their meanings of social differ, yet without being contradictory. The first orientation towards the Turing test is particularly interested in the possibility of sociality with androids. The alternate strand regards the concept of social as the intersubjectivity of agents thus its subject matter is the bonding structure that keeps agents as being participants in the collective. Researchers following the latter position are particularly interested in the emergence and evolution of society.

Bullington (2009) presents a theoretical framework and a survey of several research projects on the design of interactive agents, all of them having a particular focus on human interaction with androids. The underlying question of these projects is depicted by paraphrasing the Turing test: How can an android be designed to make a human believe he/she is interacting with another human when in reality he/she is interacting with a machine?

The theoretical framework discussed by Bullington is based on Dennett's Intentional Stance (Dennett, 1987). Dennett argues that if we are to treat something or someone as a rational agent, it is necessary to think first on what *beliefs* that agent ought to have in relation to its place in the world and purpose. Second, it is necessary to consider what *desires* it ought to have in consideration to its here-and-now. Finally, designers need to predict how the agent will act in order to fulfill its *goals*. An observer can predict what the agent would do under a given circumstance by reasoning from the set of its beliefs and desires.

When predicting the behavior of an agent we operate at three levels of abstraction:

The physical stance: at this level we are concerned with matter, physical and chemical reactions. In short, thermodynamic laws.

The design stance: at this level we deal with purpose, structure, and functionality.

The intentional stance: at this level we deal with beliefs, desires and intentions.

Bullington features two major aspects of the research on androids based on different forms of human language: conversational agents, and nonverbal communication. The former focuses on agents capable of sustaining a conversation (Cassell, 2003), whereas the latter is focus on robots and interactive characters learning and adapting from human gestures (Breazeal, 2002) and emotions (Bickmore & Picard, 2005; Picard, 1995).

The second strand of agency is agent-based modeling. This approach differs from the android perspective in that the focus of interest is in the emergence of social behavior in societies rather than of the sociality of the human-computer interaction (Epstein & Axtell, 1996; Michael J. North & Macal, 2007).

2.4.3 A definition of agents in Artificial Intelligence. In artificial intelligence, an agent is an artifact with goals. This means that any artifact, computational or otherwise, is an agent if it serves a useful purpose either to a different agent, or to itself.

In their seminal paper, Wooldridge & Jennings (1995) defined a *weak* notion of agency that involves autonomy, social ability, reactivity and pro-activeness. This notion can be extended and complemented with a *strong* notion of agency (See Fig. 2.4) that entails the possibility of having intentional actions.

Weak notion of Agency:
Autonomy: function without intervention
Social ability: interaction with other agents
Reactivity: perceive and respond
Pro-activeness: behave in a goal-oriented fashion

Strong notion of Agency:
Belief, desire, intention and knowledge

Figure 2.4 Wooldridge & Jennings notions of agency (based on Wooldridge & Jennings, 1995).

Numerous frameworks account for the understanding of agents in artificial intelligence. D'Inverno and Luck offer Structured and Modular Agents and Relationship Types (SMART) as a four-tiered hierarchical framework that accounts for a ontological hierarchy of entities, objects, agents and autonomous agents (See Fig. 2.5) (D'Inverno & Luck, 2001).

The value of D'Inverno and Luck's framework for this research resides in its potential articulation with the concept of agency from Actor-Network Theory. The above description of the SMART framework includes some translations of nouns used by

D'Inverno and Luck to prevent reader's confusion and maintain consistency with the vocabulary of concepts in the research reported herein.

In order to describe DiInverno and Luck's hierarchical framework four concepts need to be introduced:

- "An attribute is a perceivable feature."
- "An [act] is a discrete event that can change the state of the environment when performed." The original text uses *action*, but following Schutz definition of monotethic action, a discrete event is interpreted in the context of this research as an act.
- "A goal is a state of affairs to be achieved in the environment."
- "A motivation is any desire or preference that can lead to the generation and adoption of goals and that affects the outcome of the reasoning or behavior task intended to satisfy those goals" (D'Inverno & Luck, 2001, p. 18).

An *entity* is something that comprises a non-empty set of attributes, a set of actions, a set of goals and a set of motivations. It is situated in an environment and has a *state* as a function of its relationship with the environment. It also has a *stock of operations* that describe its state before and after an act is performed. D'Inverno and Luck use the word *entity* to denote an instance of an ontological class or a *thing*. Their definition of entity does not necessarily imply material or embodied instances of things. In this research an entity is named as an 'object'.

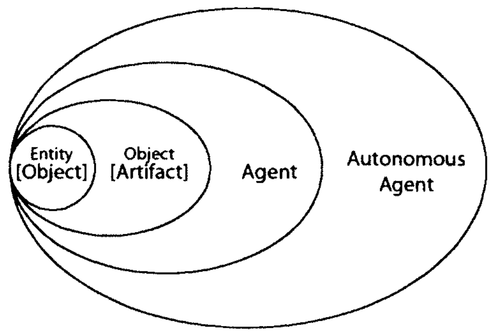


Figure 2.5 Hierarchical structure of ontologies in the SMART model (adapted from D'Inverno & Luck, 2001, p.17)

An *object* in the SMART framework has the same characteristics as an entity, but its *state* changes accordingly to a range of potential actions that such object can perform. It also has its own *stock of operations* that describes how the performance of its actions affect the environment in which it is situated. In the discourse of this research such an object is referred to as an 'artifact'.

An *agent* inherits the properties of an object in the SMART framework and it acts according to its goals. The object-agent relationship is not transitive. Agents also have mechanisms of perception and capacity for action. The agent action is a function of its goal, its actual perceptions and its current environment. Agency is also contextual, in that an agent can have a clear goal within one context but be completely useless in other context.

An *autonomous agent* is an agent capable of defining its own goals. So far the agent goals have been defined by other agent (programmed by humans), therefore the goals have been adopted from other agents rather than generated from within themselves. In order for an agent to define its own goals, the concept of motivation is introduced into the scheme. An autonomous agent is an agent with motivations and capable of defining its own goals.

Motivation is defined as "any desire or preference that can lead to the generation and adoption of goals and that affects the outcome of the reasoning or behavioral task intended to satisfy those goals" (D'Inverno & Luck, 2001, p. 28). Motivations are not states of affairs of agent attributes or capabilities. They are natural characteristics of the agent such as knowledge, which can define learning-related goals. For example, greed or power can be motivations that bias the agent's action, but such motivations are different than goals.

In conclusion, the relationships among agents in the SMART framework are defined by the adoption of goals. Entities (objects) and Objects (artifacts) are deprived of goals. Agents and Autonomous Agents can adopt a type of goal or, in the case of autonomous agents, generate their own goals. The goals that they can adopt are conditioned by their design. As an example, a cup cannot be used as a hammer. It is constrained to be used as a container because its *objectness* is not suitable to perform as a hitting tool. Nonetheless, its program is flexible enough to consent its use as a flowerpot, a tea cup or a pencil holder.

Moreover, an autonomous agent might define its goal accordingly to its motivations and situation. The capacity of adopting goals allows the introduction of the notion of society of agents as a result of the extension of an agent's capabilities through cooperation.

2.5 Human-world interaction

In this section, phenomenology and post-phenomenology are introduced as philosophical positions that account for the forms of coupling between human-technology and that explain how artifacts shape the human-world interaction. Next, the notion of affordances and constraints are discussed to explain how artifacts give shape to human action by enabling or impeding their enaction.

2.5.1 Phenomenology. The philosophical discussion about what is an appropriate framework to define technological artifacts in human experience is located in the midst of the distinction between humans and the world and how reality is apprehended. Such a distinction has branched out the philosophical thinking in diverse positions. Some place the world as a reality occurring separately from humans, who in turn dwell in the world and interpret it via mental representations. Others claim that the world and humans are the same reality, and reality is not represented but constructed as we experience the world.

In his quest for formulating a philosophy of science Husserl (1975) questioned the relative objectivity of science arguing that the interpretation of facts highly depends on the subjective position from which they are observed. Therefore, true objectivity in science is not factual but ideal. For Husserl, the most robust scientific argumentation relies on logical deductions about facts perceived, experienced or contemplated by someone that can be supported by ontological scaffoldings always referring to underlying facts in the world.

Husserl proposed that the focus of a philosophy of science should be the description of the life of the ego in relationship to those facts, which are the elementary objects of sciences. By defining a *natural attitude* of daily life, he asserted that humans naturally assume a factual world of existing beings given *a priori* as real, but such natural attitude disregards the mental consciousness of those facts (Kockelmans & Kisiel, 1970). Husserl took aside the natural attitude and reflected about the life of the ego in relationship to those facts concluding that the ego elaborates consciousness about phenomena or appearances instead of a world of facts.

For Husserl, human consciousness never exists in itself, but only as consciousness of something; it is always directed toward phenomena. This other-directness is what he called *intentionality* (Verbeek, 2005).

Intentionality, as articulated by Husserl (1975) based on Brentano's (1981) original concept, implies that every mental state is directed towards a content or object, not necessarily a thing in the world. Intentionality is deeply studied by Heidegger in regard to technology. According to Heidegger, humans use tools that enable forms of action. Such tools constitute our equipment and highly influence our way of being in the world; therefore they affect our consciousness of reality. As an example, the perceived hardness of a wall is higher if we try to scratch it with our fingernails than with a piece of metal. The experience of scratching informs us not only about the wall properties but also about the properties of the metal and fingernails. To explain this point, Heidegger contends that the object of intentionality is sometimes in the tool itself and some times in the world affected by the tool. On the one hand, it is in the tool when one's attention is focused on how to operate it, for example a drill. On the other hand, one's intentionality shifts to whatever is being affected by the tool, for example the wall upon which one is drilling the hole. In Heiddegerian terms, during the operator's action of drilling the hole in the wall, and when his/her intentionality is in the tool, the tool is *present-at-hand*. When his/her intentionality is in the wall-hole, the tool switches to *ready-to-hand*; now the wall-hole is *present-at-hand*.

Phenomenological philosophy shifts the question about where reality is to what it means for humans to be in the world. One of its main assumptions is that humans are forced to action (Dourish, 2001).Whatever action performed by a human, it responds to his/her unique and singular experience of the world. In addition, every single action is intentional and is always addressed to an object of action.

2.5.2 Post-phenomenology. Phenomenological philosophy explains how humans and the world are intertwined as the former are intentionally engaged to the latter. According to Verbeek, a new interpretation of phenomenology can take a step further and formulate that subjects and objects constitute each other. He contends that as humans experience the world it is disclosed in an specific way. Conversely, the reality in which humans are immersed determines the way they can be present to the world and each other. "In the encounter between humans and the world, each manifests itself in a particular way. In the mutual relation of humans and world there arises, therefore, a specific "objectivity" of world and a specific "subjectivity" of human beings" (Verbeek, 2005, p. 112). Verbeek coins the word *post-phenomenology* for his reinterpretation of phenomenology.

Verbeek's claim is easier to understand when it is explained in terms of technological intentionality. As mentioned above, Heidegger contends that our intentionality can be ready-to-hand when our consciousness is about the things that are being affected by the tools we use to accomplish our actions. For Verbeek, the tools are not only intermediaries of human action but mediators because they coshape the experience of the world, as a train co-shapes the way a landscape is present to human beings or computers mediate the forms of work at office environments.

Verbeek's discussion about technological mediation has two foci. First, he takes up Ihde's phenomenology of techniques to respond to the question: What roles do technological artifacts play in the manner in which human beings interpret reality? Secondly, he leverages ANT to look for an answer to the question: What role do things play in human life and action?

2.5.2.1 The structure of technologically mediated experience. In order to understand the implications of positioning technology as a mediator of human experience in the world, Verbeek makes reference to Ihde's structure of human-technology relations. Three forms of relation between human beings, technology, and the world are distinguished by Verbeek in Ihde's work (Ihde, 1990): relation of mediation, alterity relation and background relation.

Embodiment relation : (I – Technology) → World
Hermeneutic relation : I → (Technology–World)

Figure 2.6 Relations of mediation (Verbeek, 2005)

Relation of mediation is that in which human intention is addressed towards the perception of the world via an artifact. This type of relation has two possibilities. On the one hand, *embodiment relations* are those in which the body is extended or augmented by the mediating artifact. As an example, a jacket enhances the human body protection against cold. On the other hand, *hermeneutic relations* are those in which the artifact represents the world in a conventional language, as the thermometer translates temperature into a value in a measuring scale. In other words, artifacts are translators of the world phenomena into a readable form for human interpretation.

Alterity relation is that in which intentionality is addressed towards the artifact that performs an action affecting the world. According to Verbeek "[t]he role played by technologies in this set of relations can be characterized as that of a 'quasi-other'" (Verbeek, 2005, p. 127). Furthermore, Verbeek contends that humans often approach technologies in anthropomorphic ways, caring for artifacts like cars or assuming otherness in computers. A similar conclusion was derived by Reeves and Nass (1998) from their research on how people treat electronic media devices. In addition, some technologies can elicit a sense of autonomy providing advice to the human counterpart. Nonetheless, Verbeek clearly states that technology is never a genuine other. Operating the drill, in the example above, would be an instance of an alterity relation.

Alterity relation : I → Technology(– World)

Figure 2.7 Alterity relation (Verbeek, 2005)

Background relation is a relation in which humans are unaware of the artifacts that operate in their environment, but are affected by their operation. As an example an air conditioner in a room is constantly operating but we are unaware of its action. The presence of such artifacts becomes explicit when they break down.

Background relation : I (– Technology / World)

Figure 2.8 Background relation (Verbeek, 2005)

Verbeek discusses mediation in relation to post-phenomenology by differentiating *direct* and *indirect* forms of mediation. Direct mediation is related to technologies that transform perception. Verbeek claims that a multiplicity of realities emerges from sensing the world with different tools. Indirect mediation is related to the cultural or hermeneutical perception of the world, opening an area of research on the interpretation of socially constructed reality. According to Ihde (1990) these two are intertwined and non-exclusive forms of mediation.

2.5.2.2 Artifacts as nonhuman actors. ANT and post-phenomenology have two different perspectives on how to understand the subject-object dyad, however they are complementary. Whereas ANT denies the existence of any ontological gap between these two components, phenomenology and post-phenomenology acknowledge it and try to understand their relation claiming their intertwined condition. Such contradictory position does not prevent the finding of mutual contributions. ANT provides a fresh approach on the network analysis and an appropriate vocabulary with which to analyze the mediation of action. In addition, post-phenomenology contributes with a framework for the analysis of the experience of action, and hermeneutical interaction.

From the meanings of mediation defined by ANT, the subject-to-object delegation of programs-of-action and the translation of actants' programs-of-action into new ones provide significant insights to support the post-phenomenological idea of subject-object co-shaping.

2.5.3 Affordances and constraints. The concept of affordance is a central component of Gibson's ecological approach to psychology (1979/1986). Gibson describes affordances as the function of what the environment affords expressed as information perceived by animals and humans that cognitively adapt their behavior. Wells (2002) subsumes the characteristics of an affordance in a framework of features, of which the more relevant to this research are the affordances that are ecological, are relational, are meaningful, and sets of them constitute niches.

Affordances are *ecological* in that embodied action is enacted within an environment. The definition of what constitutes the environment of action is a function of the animal's bodily capacities. All of the perceivable attributes of the environment are information for action if they match the animal's capacities. However, some attributes are constraints in the sense that they impede viable forms of action (Norman, 2002; Shaw & Turvey, 1981; Wells, 2002).

Affordances are *relational* in the sense that they mutually complement the environment and the animal. Gibson contends that the affordance is not a third entity emerging from the relation between environment and the animal. Rather, the affordance resides in the world and it is brought forth in the environment-animal relationship as meaning. "The *affordances* of the environment are what it *offers* the animal, what it *provides* or *furnishes*, either for good or ill. ... It implies the complimentarily of the animal and the environment" (Gibson, 1979/1986. Cited by Wells, 2002. Emphasis in original).

Affordances are *meaningful* because to perceive them is to perceive what they afford. For Gibson, values and meanings are perceivable directly from the world, that is, they do not need an observer to be endowed to an artifact; rather they are a function of the artifact's materiality.

Gibson makes a distinction between *habitat* and *niche*, The former is the set of environmental characteristics that allow the evolution of an animal, whereas the latter is the set of affordances in the same environment that furnishes information for the animal's action.

Although the definition of affordance appears intuitive, defining a *constraint* is somewhat more complicated. To afford has a positive connotation and compels for action, whereas to constrain is to limit. To afford is about the possibility of enacting planned states of affairs setting the temporality of any possible action in the future. The constraints arise subsequently. This temporal difference renders the intuitive affordance-constrain opposition hard to conceptualize. Greeno's (1994) analysis of affordances provides a clarifying framework in this regard. Greeno holds that constraints are dependent on situational conditions, that is, that the meaning of a constraint is contingent to the current, actual or inferred state of affairs. As an example, picking up a coffee mug from the table could be done by holding it from either its body or from its handle because both elements afford that projected action. However, if the body is too hot, the remaining feasible affordance is the handle. The projected action anteceded the realization of constraint. The mug's body temperature is a *conditional constraint*.

2.5.3.1 Affordances in design. The relevance of Gibson's concept of affordance in design relies on the introduction of the context in the perception-action process. The symbolic cognitive model states that human action happens when we articulate perception with memory to generate a symbolic representation of the environment, which is completely a mental operation. In contrast, Gibson contends that information is scripted in the world enabling forms of action suited for human's physical and cognitive capabilities. Therefore, people perceive the world as the environment of potentialities for action. In design terms, a good design depends on the quality of its affordances. Therefore, artifacts designed to clearly convey their potential utility and operability are better designed, from a *user-centered* perspective.

Gaver elaborates on Gibson's work highlighting how potential action is distributed between the "acting organism and the acted-upon environment" (W. W. Gaver, 1991, p. 80). To Gaver, *perceptibility* is the right approach to make systems easy to use, in particular computer-based systems. By perceptibility Gaver understands the affordance's degree of manifestation and the accuracy of its message. Such perceptibility is influenced by the participant's culture but Gaver claims that culture does not constitute part of the affordance. That is to say that the affordance is the same regardless of the participant's cultural experience.

Complex functions require complex actions. A function is complex when the participant cannot predict how the system would work in order to achieve the final goal. In contrast to the straightforward hammer's affordances, computational systems are not easy to understand because the participant cannot figure out an action plan to reproduce an MP3 file if he/she has never interacted with the device before. Consequently, a complex action is an operation that unfolds as it goes. Gaver defines *nested affordances* as such affordances that, acting upon them, reveal new affordances. For example, a button displaying a contextual menu from which the participant makes a selection. The button affords to be clicked, after that action a list affords items to be selected. In addition, Gaver defines *sequential affordances* as the affordances that require multiple sequential actions to achieve a goal. For instance clicking on the scrollbar and then dragging (W. Gaver, 1991).

User-centered design, as proposed by Norman (2002; Norman & Draper, 1986), offers a perspective on the design of artifacts and its affordances. It leverages on methods of user study to understand how the users of a system develop conceptual models, map the relationship between a tangible control and the controlled target, and get feedback from the system. The definition of affordance elaborated by Norman claims that the affordance interpretation is the result of the mental processing of the perceived world. This definition differs from Gibson's who argues that meaning is perceivable directly from the world. In Norman's words "affordances result from the mental interpretation of things, based on our past knowledge and experience applied to our perception of the things about us" (Norman, 2002, p. 219).

Norman's cognitivist theory of action offers an approximated model of planning, enacting and evaluating actions. It constitutes a framework for design which argues for four design strategies that are consequent with Gaver's ideas: make visible the current status of the system, understand user's conceptual models, map correctly user's model and system's model, and provide feedback of the actions performed.

In the context of interaction design, Norman's definition of affordance has been generally accepted. However, he himself asserts that it diverts from Gibson's definition. Hartson (2003) bridges the dichotomized understanding of what an affordance is by explaining that Gibson's *affordance* is the physical characteristics of an artifact that allows its operation. Whereas, Norman emphasizes in *perceived affordance* arguing that it is the perceivable device's attributes that clue the user in on the operation.

Hartson explains the difference between the two kinds of affordances by associating them to the role they play in supporting the participant's interaction. In that strand, Hartson renames Gibson's *affordance* as *physical affordance* because it helps user with their physical actions. Norman's *perceived affordance* is renamed as *cognitive affordance* because it helps the participant with the cognitive actions. In addition, Hartson introduces two new kinds of affordances: *sensory affordance* which helps users with their sensory actions and finally *functional affordance* that "ties usage with usefulness" (Hartson, 2003, p. 316).

But why is it necessary to break down Gibson's original idea into that many pieces? What is the value of separating sensation, perception and cognition, and describing action from these four aspects? Hartson argues that having these aspects separated is useful for HCI design and analysis because the traditional psychological approach, which intertwines them, does not consent the necessary level of abstraction that allows the analysis of single interface design elements. As an analogy, legibility is about the distribution and size of characters in a paragraph but is not related to the meaning of the text. Thus, when analyzing the text as a sensory affordance we deal with its perceptual aspects, not with hermeneutical aspects.

As for Norman's question: How do you know what to do when you see something –a device– you have never seen before? Hartson contends that the required "information is in the world: the appearance of the device could provide critical clues required for its proper operation" (Hartson, 2003, p. 320). However, not all the information is available in a tangible form; other visual forms use cultural grounded language like written or graphical instructions. Furthermore, Hartson proposes the User Action Framework, which frames the different types of information in the world. The framework is composed of four kinds of affordances that this research structures as a class hierarchy (See Fig. 2.9). The initial affordance class is the *sensory affordance* defined as "a design feature that helps, aids, supports, facilitates, or enables the user in *sensing* (e.g., seeing, hearing, feeling) something" (Hartson, 2003, p. 322). In addition, the *cognitive* and *physical affordances* inherit the property of affording sensing, which is to say that all cognitive and physical affordances are sensory affordances as well. A *cognitive affordance* "is a design feature that helps, aids, supports, facilitates, or enables *thinking and/or knowing* about something." It includes the texts and signs in the device. A *physical affordance* "is a design feature that helps, aids, supports, facilitates, or enables *physically doing* something" (Hartson, 2003, p. 319. Emphasis in original).

Finally, Hartson defines *functional affordance* as a higher-level affordance, which encompasses the utility of the artifact that contains either cognitive or physical affordances. As an example the door is a functional affordance that allows passage but it contains other affordances like the doorknob, which is a physical affordance that allows the user's operation of the door.

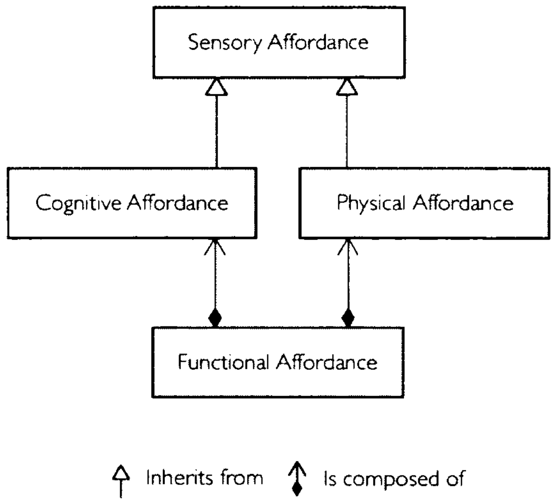


Figure 2.9 Class structure of Hartson's affordances (based on Hartson, 2003)

2.6 Computer mediated interaction

The whole spectrum of HCI and interaction design principles and realms is vast and it is not in the scope of this dissertation to cover all of them. This research is focused on ubiquitous computing as the field to which this research topic belongs. In this section the ubiquitous computing field is defined and two characterizing frameworks are introduced: Smart DEI and Implicit Interaction.

2.6.1 Brief notes on the history of ubiquitous computing. The disappearing computer concept, as proposed by Weiser (1991) twenty years ago, consists on shifting the focus of computing from the desktop to the environment enabling new forms of interaction with digital data. This simple but compelling vision started with the exploration of interconnected pads, tablets and large screens as new forms of computing devices. Later on, it became a prolific research trend in labs all over the world bringing forth innovative products and forms of human-computer interaction (Streitz, 2007).

Weiser's pioneering work proposed the concept of *Calm Computing*, which suggests the shift of the computing focus from the center to the periphery, embedding computers in the surroundings of the traditional places where they used to serve. The project *Things That Think*, developed at MIT, looked at how the physical world meets the logical world or the virtual computerized world. One of its results is *Lego Mindstorms* (Mindell, 2000), a toy like programming language based in tangible building blocks. Instead of programming software by typing lines of code, the child arranges material blocks in logical sequences; certainly, a more intuitive and embodied form of programming. Moreover, Ishii continued a branch of *Things That Think* in his own program named *Tangible Bits* (Ishii & Ullmer, 1997) in which he explores the idea of moving intelligence, sensing, and computation into things. His contribution takes advantage of multiple senses and multimodal human interaction. Later on, the Japanese electronics manufacturer Sony introduced *DataTiles* (Rekimoto, et al., 2001), an interactive user interface that uses task-specific physical artifacts as alternatives to manipulating virtual information systems. This idea, as well as *Tangible Bits*, moved computer interaction from the WIMP – windows, icons, mouse and pointer – paradigm to exploration of additional haptic skills to manipulate artifacts, not only clicking and pointing, but also rotating, grasping, attaching and other gestural interactions. Furthermore, Wearable Computing also followed Weiser's intention of displacing computing to the periphery, but in this case it was in the form of mobile devices hosted on the human body as helmets, glasses or garment. Among its applications there is the monitoring of the body's functions, surveillance and augmented reality. Finally, the most extreme case of the disappearing computing consists in implanting microcontrollers into living bodies giving rise to cybernetic organisms.

2.6.2 Smart Devices, Environments and Interactions (Smart DEI). Making computing power pervasive implies new challenges for the design of interfaces. The design problem is to constitute a cohesive solution that articulates the human body and its cognition capacities, the attributes of the space where those capacities are used, and also the ubiquitous access to data in the world. Poslad (2009) offers *Smart Devices, Environments and Interactions* (Smart DEI) as a framework that characterizes ubiquitous computing (UbiCom) based upon: design architectures, an internal model of the UbiCom system, and a model of the UbiCom system's interaction with its environment.

2.6.2.1 Design architectures. Poslad's Smart DEI framework proposes three main types or architectures: smart device, smart environment and smart interaction. The word *smart* simply refers to an entity that is active, networked, and to some extent autonomous.

Smart devices are artifacts that serve as portals to access sets of applications. Their locus of control and interaction resides in the devices themselves. The devices are archetypically configured as tablets, pads or boards. Tablets and pads are mobile devices aware of their location using GPS technologies.

Smart environments are those that are able to get and apply information from their situation and their dwellers in order to facilitate their actions. They are constituted by interconnected smart devices that may act in the following forms: tagging participants, sensing the physical environment, creating representations of the physical situation, adapting, regulating and controlling the environmental conditions.

Smart interaction is the functionality of the UbiCom system to dynamically organize and adapt itself to act collectively with other smart devices. Interacting smartly gives flexibility to the UbiCom system because the smart devices are usually designed as single function devices that need to be composed as aggregates in order to extend their individual functionalities. Two types of smart interactions are distinguished:

- Basic interaction: the protocols and conditions for interactions are established and preset before the interaction happens. Basic interaction can be synchronous or asynchronous.

- Smart interaction: the protocols and conditions are defined as the interaction unfolds. Smart interaction requires coordination, policies and conventions, semantic and linguistic interaction.

2.6.2.2 Internal model of UbiCom systems. Central systems such as early desktop computers had the advantage of being unaware of the environmental conditions except for the keyboard or mouse. That is not the case for UbiCom systems. The complexity of distributed computing poses a challenge in modeling the system. The properties of these systems are:

Distribution and heteronomy: constitutive smart devices are disperse in the environment and vary in their kind. Some of them are sensors, other actuators and some are hybrids.

Implicit human-computer interaction: much of the information transmitted in natural communication between humans is non-verbal, contextual and indexical. For example, when two people in an elevator need to get off at the same floor an implicit turn-taking process happens between them with no verbal language involved. In contrast, explicit interaction is an overt action that triggers the course of action towards a desired state of affairs.

Context-awareness: in order to enable, disable or adapt their services, UbiCom systems need to be are aware of the *physical context* conditions such as temperature, dimensions, luminosity, time. They also need information of the *human context*, i.e., identity, social situation, types of user. Finally, an additional layer of *technological context* provides information about the services available at the system's current location.

Autonomy: a system adhered to a policy or a goal is autonomous if it is capable of adapting itself and making a decision about its state independently. This facilitates the reduction of human interaction and maintenance.

Intelligence: an autonomous system does not necessarily exhibit intelligence because autonomy can be achieved by following protocols enacted as the result of simple *if-then* statements. Instead, intelligent systems take proactive actions dynamically based on models of the situation, the task and the user.

2.6.2.3 A model of UbiCom system's interaction with its environment. As described above, the UbiCom system simultaneously inhabits three types of context: physical, human, and technological. Together they constitute the system's environment. In order to elaborate a model of such multidimensional environment Poslad suggests the separated analysis of the system's interaction as a function of its participation in the human-to-human interaction and its role as mediator between the physical and the virtual world.

The former describes a spectrum of interactions ranging from face-to-face human interaction to computer-to-computer interaction. The latter describes a spectrum from direct physical interaction to virtual reality facilitated by ubiquitous computers.

2.6.3 Implicit and explicit interaction. Human computer interactions are classified as explicit and implicit according to their specificity and clarity. *Explicit interactions* put the user at the center of the activity controlling the interaction dynamic. Minimal or no initiative is taken from the machine side. The system's interface design is tightly aligned to accomplish the user plans and goals. Alternatively, *implicit interactions* are those unfolded in the indirect but complementary interaction between the system and the user. Schmidt defines them as "an action performed by the user that is not primarily aimed to interact with a computerized system but which such a system understands as input" (A. Schmidt, 2000, p. 2).

Schmidt's approach to implicit interaction is application-oriented. His definition of this type of interaction principles is centered in the perception and interpretation the UbiCom system needs to do in the situational context. Knowledge about the situational context is fundamental to the application adaptability. By situational context Schmidt means the state of aspects of the setting where the application is running such as time, user type, physical environment, social setting and system goals. Mechanisms for capturing situational context and making decisions for action are described in a simple algorithm as:

- Create a set of surrounding conditions C to be sensed and a void set of devices D

- For each condition determine its accuracy, update rate and appropriate sensing device
- If the cost of using that device is acceptable, then add that device to *D*
- If *D* is not void, then for each device reading pair an appropriate reaction *R*
- Execute *R*

Finally, Schmidt proposes an XML-based markup language for the processing of implicit HCI based on situational context. XML language is easily human readable and also easy to process.

Ju and Leifer offer a more human-centered approach on implicit interactions. They characterizes implicit interactions as "those that occur without the explicit behest or awareness of the user" (Ju & Leifer, 2008, p. 72). This definition presents a different nuance from Schmidt's in that it contends that operations happening in the background and initiated autonomously by the computer, such as auto-saving, are instances of implicit interactions.

Ju and Leifer offer a framework for characterizing implicit interactions as a function of *attentional demand* and *initiative*. On the one hand, user's attentional demand ranges from foreground attention to background attention. On the other hand, participants' initiative in the interaction range from reactive to proactive. Interactions initiated by the user are reactive interactions, and interactions initiated by the system are proactive interactions.

CHAPTER 3

THEORETICAL-CONCEPTUAL FRAMEWORK

3.1 Material mediation of social practices

A social practice is an array of human activity bounded by shared practical understanding (Schatzki, 2001). Some post-humanist thinkers (Callon & Law, 1995; Latour & (Jim Johnson), 1988) contend that the analysis of a practice would be imperfect unless it accounts for how artifacts mediate human activities. They argue that we are increasingly living in an object-centered society (Knorr-Cetina, 1997) where artifacts take on significance through their roles not only as equipment, but also as mediators, elements of cohesion, or commonplaces of identity characterization. In this strand of thought, artifacts are not merely tools or commodities but *activity partakers* in human-artifact collectives.

While the design of artifacts is traditionally framed as a user-centered design problem, the design of human-artifact collectives can be defined as a practice-centered design problem. A practice-centered approach to design is focused on the continuously co-evolving relation between human and nonhuman actors jointly implicated in the process of "doing" (Ingram, Shove, & Watson, 2007). While the user-centered design perspective denies the ascription of control to artifacts by assuming humans as the acting party (the “doers”), a practice-centered design is open to distributing the system's action (the "doing") in a network of actors that includes artifacts. A practice-based design approach repositions humans as *the users of* and recasts them as *among the participants in* a network of actors. This frames the design and study of artifacts in terms of their actions within a network of social participants. This not only extends the scope of the human-machine model in interaction design, but anchors a strand of research on the participation of things in society as assistants, agents, delegates, signifiers, mediators or intermediaries. It also opens onto fundamental contributions which are primarily oriented towards expanding the domain of interaction design beyond its current limits of instrumental goals, distributed ubiquitous computing systems, and mediating social interaction.

3.2 Mediating meaning in practices

This research envisions Knorr-Cetina's (2001) concept of object-centered sociality, founded on her definition of *knowledge objects,* as a conceptual framework with the potential to extend the user-centered approach – especially in the design of interactive systems. In order to prepare this idea of sociality for use in creating a model for the design of mediating artifacts, it will be honed against some of the models offered by Fiske's in his Relational Models Theory.

As explained in Chapter 2, the mathematical theory of binary relations provides definitions and properties useful in describing interpersonal relations (De Soto & Kuethe, 1958). Fiske (Bolender, 2010; Fiske, 1992) elaborates on that theory to formulate his Relational Model Theory that accounts for the norms, motives and moral principles that underlie interpersonal relations, in other words the forms of human sociality in the context of this research.

Fiske argues that:

> [M]otivation, planning, production, comprehension, and evaluation of human social life may be based largely on combinations of 4 psychological models. In *[C]ommunal sharing*, people treat all members of a category as equivalent. In *[A]uthority ranking*, people attend to their positions in a linear ordering. In *[E]quality matching*, people keep track of the imbalances among them. In *[M]arket pricing*, people orient to ratio values. Cultures use different rules to implement the 4 models (Fiske, 1992, p. 689. Emphasis in original).

Fiske's argumentation is especially useful to characterize interpersonal interactions across different forms of sociality because it relies on principles that are not specific to any one culture, and regards members of a social group as value-laden individuals whose social actions are heavily biased by the group's dominant sociality. But an attempt to extend Fiske's socialities to human-artifact socialities appears nonsensical. At least it seems illogical to argue for a computational machine entitled to the same social obligations or privileges as the ones to which humans are entitled. However, from a post-humanist perspective it is plausible – and necessary – because sociable robots and smart artifacts participate in social interactions with humans and thus deserve a different consideration. The contexts where smart artifacts operate currently with humans include such diverse areas as assisting patients in medical facilities, reminding people to take their medications, mediating work between employees, helping parents watch their kids after school, connecting couples over long distances, and easing commute driving for suburban workers – and in the near future they will become even more involved in many forms of hybrid sociality.

Even though artifacts may not be entitled to privileges and obligations, they can be designed to reify social norms, motives and moral principles. Latour famously uses a speed hump as an example of how things reify such aspects of human sociality. A speed hump located on a neighborhood street forces drivers to slow down, it reifies the desire of the neighbors to keep their children safe from cars, and represents the neighbors' authority over streets, even though drivers are entitled to drive freely in the city. It is in the scope of activities interrelating several actors – parents caring for their children, one; children playing on the street, two; while drivers, three; commute in their cars, four – where the speed hump reveals its moral facet. It is in such scope where multiple parties engage in interrelated activities and artifacts perform as actors by mediating the actions of other actors. In such a scope, the meaning of a *media artifact*, i.e., a mere vehicle of content, encompasses the problem of mediating human action, redefining such an artifact as a *mediating artifact*, and thus revealing its capacity to act. Such scope of "embodied, materially mediated arrays of human activity centrally organized around shared practical understanding" is what contemporary social theory defines as a *practice* (Schatzki, 2001).

Knorr-Cetina's object-centered sociality offers a standpoint on how artifacts participate in human society that, although it differs from Fiske's socialities, they complement to each other from a design stand point. Knorr-Cetina's idea of sociality is structured along the fundamental assumption that knowledge and technology are the dominant forces that define contemporary society. Individuals in an object-centered society look for the construction of socially accepted and practical truth. People are affiliated with several communities of practice, each of which gravitates around objects of knowledge. Knorr-Cetina defines these objects as incomplete and constantly unfolding units positioned at the center of society's structure. Knowledge objects are not limited to physical things, they can also be *instances of subjects of inquiry* – such as procedures, techniques, methods and other things which can be studied by the group – that elicit new questioning in the community of practice to which they belong.

Fiske's four relational models provide a solid framework to characterize interpersonal interactions within systems of norms and moral principles. But artifacts, according to Fiske's definitions, are limited to commodities or tokens of emotional value, disregarding their mediating capacity. This research argues for material components of a society that have a more meaningful and relevant role in how humans socialize. It takes Fiske's elementary forms of sociality as a complementary framework to Knorr-Cetina's object-centered sociality and envisions mediating artifacts as material instantiations of knowledge objects. Such material instantiations promptly participate in the ongoing activity to which they are enrolled if they have embedded sensors and actuators. More specifically, such material instantiations can signify the underlying moral principles of the practice in which they are involved and support individuals who play according to the community's dominant sociality. The objective of this chapter is to set a theoretical conceptual basis with the aim to elucidate how mediating artifacts may participate in such social practices.

3.3 Networked artifact mediation

In addition to Actor-Network Theory (ANT), there are several other theoretical strands that study how human activity within a practice is mediated by the material environment in which the activity occurs (see e.g., Kaptelinin & Nardi, 2006; Thévenot, 2001). Actor-Network Theory is the most suitable conceptual framework for this research because it encompasses humans and nonhumans within an ecology of actors. Moreover, this research's attempt of positioning mediating artifacts as signifiers of the community's dominant sociality is aligned with ANT's idea of symmetrical actors – humans and nonhumans both – pursuing their programs-of-action by mediating social interaction in the network.

The minimal requirement to be a participant in a network of actors is to be present within the social domain while a course of action unfolds. By being present, a participant gets *subscribed* to the network. This means that he/she/it is now a new node in the network that can influence the actions of other agents because he/she/it is regarded as a potential actor with whom they can establish new associations. A network of actors can be rich in actors but poor in actions if actors are passive. Conversely, a few actors can perform many actions, rendering the network very vibrant. It is assumed that each actor is an agent who tries to execute his/her own program-of-action in a social domain. Artifacts also enact their own programs-of-action. But, as it will be explained further, only *smart artifacts* exhibit an extended autonomy derived from their human counterparts. In a social practice, actors act on their own to procure the goal of their programs-of-action, but the collective outcome is not necessarily a competitive game where each one tries to maximize their payoffs. The result, instead, is a stable imbroglio of activities in which dominant, morally-laden logics determine which activity is the most socially rewarding.

3.4 Structuring social interaction in human and smart artifact collectives

3.4.1 A definition of smart artifact. A smart artifact is a programmed agent that autonomously acts in the world by adapting its own structure while preserving its organization. Every smart artifact is designed with one or more programs-of-action. In doing so, its designer defines the artifact's organization and structure. The structure of a smart artifact is twofold. First, its hardware, composed of i) a set of sensors that perceive the artifact's own state and that of other social actors, plus ii) a set of actuators which support or constrain its interaction with other actors. Second, its software, which aims to determine the most suitable actions to support the activity in which it is involved.

3.4.2 Human and smart artifact collectives. As discussed in Chapter 2, humans and smart artifacts constitute a collective when they articulate their programs-of-action. By articulation, Latour means the crafting of a collective as a new entity with its own hybrid program-of-action. The resultant collective is a compound social actor whose actions affect the actions of other concurrently-participating collectives in the network. The effect of the collective's hybrid program-of-action in the network is greater than the simple aggregation of programs-of-action of the constituent actors.

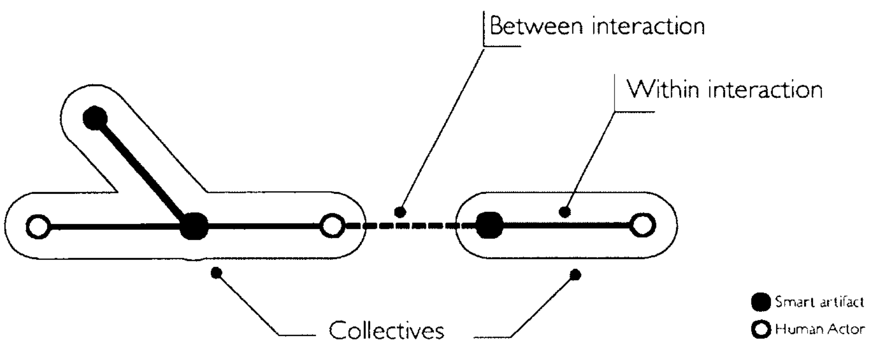


Figure 3.1 *Within interaction* and *between interaction* of networked actors

In order to propose an actionable theoretical framework for the design of socially apt smart artifacts, the analysis of social interaction will be split into i) interactions *within* the collective, and ii) interactions *between* collectives (See Fig. 3.1). **Within** a collective, both human and smart artifacts interact by articulating the mediating meaning of the collective. **Between** collectives, each collective appears to its counterpart as a single social entity.

3.4.3 Interaction within collectives. A design analysis of the interaction of humans and artifacts within a collective presents a double-edged mediation. On the one hand, the mediation constructs a meaningful, compound social actor by articulating both the human's and the artifact's programs-of-action. On the other hand, the mediation also locates the human actor's intentionality in the collective or in the actor-network. The former facet is defined as the *assembly of meaning*, and the latter facet as the *mediation of intentionality*. From the perspective of the assembly of meaning, mediation is characterized by Latour's four types of meaning mediation: translation, composition, black-boxing and delegation. These types, described in Chapter 2, account for how the articulation of hybrid programs-of-action operates.

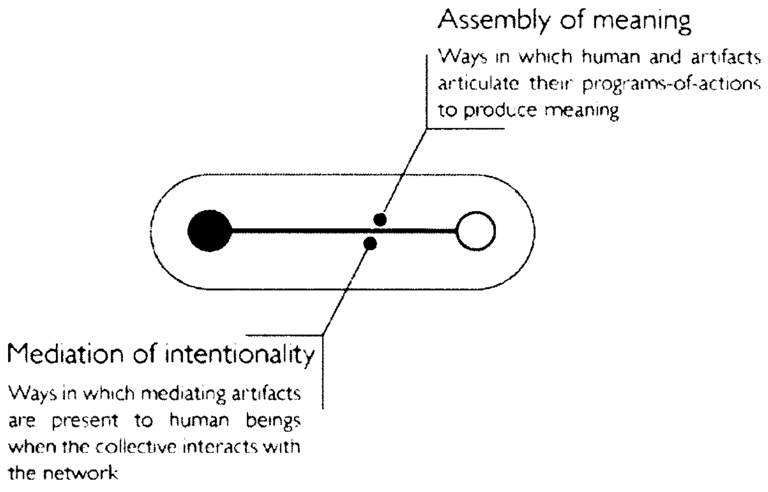


Figure 3.2 Double-faceted *within interaction* of collectives

From the perspective of the **mediation of intentionality**, Ihde (1990) elaborates on Husserl's concept of intentionality (Kockelmans & Kisiel, 1970) to put forward four *relations of mediation*: background, embodiment, hermeneutic and alterity relations. The relations of mediation shape a continuum that represents different levels of human awareness of an artifact's presence when it mediates the interaction between humans and the world. Such a continuum depicts different levels of *presence* amongst the members of a collective (See Fig. 3.3). When members are present, their actions are overt. When members are non-present, their actions are covert, but they still affect the collective-world interaction.

Let us analyze the possibilities of artifact presence in the continuum. In Figure 3.3, the left end of the continuum, the artifact acts in the background and the human actor is not aware of it. As we move to the right, the artifact's presence gradually bubbles up to the foreground of the human's awareness, from being a non-present actor to being present as a component of an embodied agent, then as a hermeneutic agent, and finally to constituting a distictive present-at-hand agent. Next, let us locate human intentionality in the continuum. At the left end of the continuum, the noema – the object of intentionality – is outside the collective; it targets the network's activity. On the opposite side, the noema is inside the collective; it targets the smart artifact party of the collective.

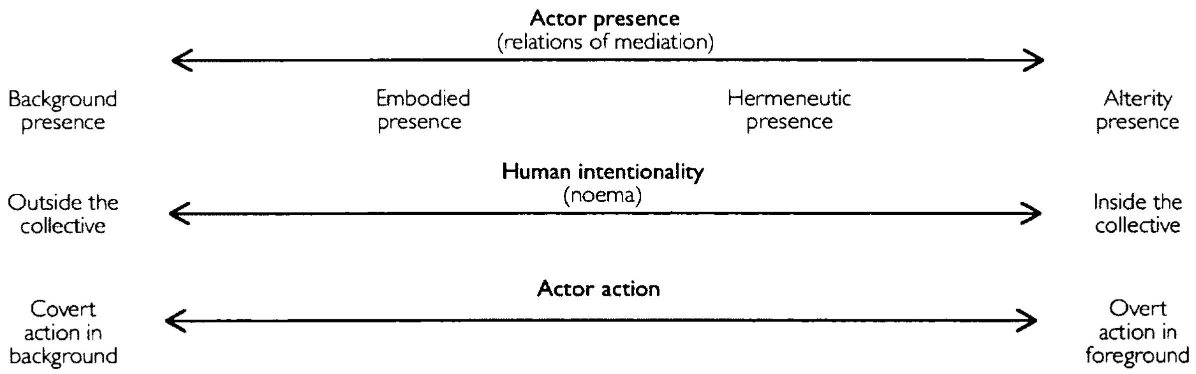


Figure 3.3 Continuum of human-artifact presence within a collective

To illustrate the mediation of intentionality with some examples, the interaction of a driver with her car on a drive through a neighborhood is mapped in Table 3.1. The extreme left interpretation on the continuum regards background relations: a human and a smart artifact interact, but the human is oblivious to what the smart artifact does. In our example, the car's air conditioner unit constantly adjusts the interior temperature while its driver is unaware of its operation. The driver's intentionality is on the driving conditions of the neighborhood streets, not on the air conditioner's affordances.

Table 3.1 Framework of human–artifact mediation within a networked collective.

Assembly of meaning Ways in which human and artifacts articulate their program-of-action to produce meaning	Mediation of intentionality Ways in which mediating artifacts are present to human beings when their collective interacts with the network			
	Background	Embodiment	Hermeneutic	Alterity
Translation	-	-	Speedometer	-
Composition	-	Honking the horn	-	-
Black-boxing	Air conditioned	-	-	-
Delegation	-	-	-	Door lock

The second interpretation regards embodiment relations: a human and a smart artifact together embody a single agent which pursues a program-of-action. For example, when the driver honks the car's horn she alerts pedestrians and other drivers, not only of her presence but also of the presence of the driver-car entity as a compound agent. The driver's intentionality is on warning pedestrians and other drivers about her own actions, not on the horn's affordances. Another example of this interpretation is the way cybernetic individuals put forward their internal condition with wearable technologies (Schiphorst, 2006).

The third interpretation regards hermeneutic relations: a human reads what the smart artifact interprets. For instance, the speedometer represents the driver-car speed in meaningful speed units. The driver's intentionality is on the relationship between the speed represented by the dashboard's speed needle, and the speed limit posted by the government.

The fourth interpretation on the extreme right regards alterity relations: a human regards the smart artifact as a quasi-other with whom it is possible to establish social exchanges (Breazeal, 2002). In the driver-car example, the driver locks the back doors, delegating to the car the safety of children in the back seat. The driver's intentionality is on keeping passengers safe inside the car.

The two facets of human-artifact interaction within a collective can be mapped within a conceptual framework (Table 3.1). This framework can be used as a design tool for the articulation of programs-of-action between smart artifacts and humans, as well as the study of ways in which mediating artifacts are present to humans when they interact in a network.

3.4.4 Interaction between collectives. In the previous section, the theoretical structure for the design and analysis of tangible social mediators within a collective was defined. This section offers a framework for the characterization of the forms of social interaction between collectives. Because this research is interested in assessing how people manage to preserve or restore social balance, it is focused on cooperation and collaboration, which are forms of social interaction based on equivalence socialities. The analysis conducted here does not cover the interactions of hierarchical-based socialities, because that would lead to measuring the social distance between parties, instead of studying the preservation of balance between them.

Many classifications of social interaction have been proposed in literature: competition, conflict, accommodation, and assimilation (Park & Burgess, 1966); subordination, superordination, exchange, conflict and sociability (Simmel & Levine, 1971); cooperation (Axelrod, 1984; Fehr & Gächter, 2002); cooperation and coercion (Nicholson, [1934] 2004), among others. This research elaborates on cooperation and collaboration, which work in concert with the underlying moral values of equivalence-based socialities such as Fiske's Communal sharing and Equality matching relational models. Competition, subordination, super-ordination, and coercion are typically observed in hierarchical relational models like Authority ranking and Market pricing.

The moral values of Communal sharing and Equality matching are clearly visible when people claim privileges or demand others to fulfill obligations. People tend to fall into one of three patterns when resources are limited or scarce: conflict, cooperation or collaboration. Conflict can be prevented by coordinating balanced access to resources. When people coordinate their actions, they end up in either cooperative or collaborative activities. Coordination in desired balances has been extensively studied in game theory by analyzing variations of games that are essentially composed of players, strategies and payoffs (Axelrod, 1984; Polak, 2007; Von Neumann & Morgenstern, 1953). Researchers generally agree that the best scenario for players who try to maximize their payoffs in a game is described by the game's Nash equilibrium[8]. Such equilibrium can be achieved when players play their best response to the strategies of other players.

A different but complementary approach to coordination is shown by Schmidt and Simone's study of artifacts mediating cooperative work (K. Schmidt & Simone, 1996). Schmidt and Simone conclude that artifacts and protocols facilitate the articulation of work and alleviate the need for *ad hoc* deliberation and negotiation. Unlike game theory, their discussion is not focused on how people maximize their individual outcomes, but rather on how people mesh interdependent activities that occur on a common *field of work*. In their study, workers can be regarded as members of a Communal sharing group entitled to equal privileges on the field of work, but their obligations are scaled to match their capacities.

Cooperation and collaboration are fundamental forms of social interaction based on the perception of equivalence between the interacting parties. As a result, the forms of interaction **between** collectives explored in this research are cooperation and collaboration (See Fig. 3.4).

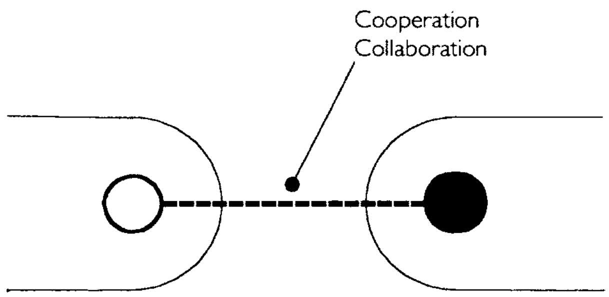


Figure 3.4 Interaction between collectives

[8] In game theory, the strategies played by two or more players exhibit a Nash equilibrium when all the players execute individual strategies that maximize every one's payoffs.

The definitions of cooperation and collaboration are not uniform across the literature. They usually overlap or are synonymous. Etymologically, it is difficult to contrast their roots because they are twin words. Both cooperation and collaboration come from *com-* "with" (see com-) + *operari* "to work", which is also *laborare* (Harper, 2001, 2012). To clarify in what sense this research uses these words, custom definitions are provided. Such definitions are based on the researcher's observations of interactions between collectives made in pilot experiments with mediating artifacts. Three aspects define the interaction between collectives: i) the directionality of the goals between the interacting parties, ii) the compatibility of their programs-of-action, and iii) their consideration for other's interest. The *directionality of the goals* of interacting parties is consequent when the achievement of one's goals does not harm the achievement of other's goals. On the contrary, the goals' directionality conflicts when the achievement of one's goals disrupts the achievement of others. The *compatibility of the programs-of-action* of actors is defined by the affinity of their goal-achievement methods. If their methods harmoniously share resources such as time or place, their programs-of-action are congruent, otherwise they are discordant. Finally, actors' *consideration for others' interest* are altruistic when they care for each other's goal achievement, and it is selfish when their only concern is the achievement of their own goals.

Different combinations of these aspects of interaction between collectives produce different kinds of social results. It is more likely to observe collaboration between actors when their goals are consequent and their methods are congruent. On the other hand, cooperation emerges when actors' goals conflict and their methods are discordant. The consideration to others' interest is a psychological aspect that may change over the course of the interaction. The consideration for others' interest is tightly related to the relational model underlying the social interaction. Communal sharing is inclined towards altruism, whereas Equality matching favors selfishness (see Chapters 4 and 5).

Table 3.2 Summary of aspects of social interaction between collectives

Social interaction	Aspects of interaction between collectives		
	Directionality of goals	Compatibility of programs-of-action	Consideration for others' interest
Collaboration	Consequent	Congruent	Altruism
Cooperation	Conflicting	Discordant	Selfishness

The following definitions of collaboration, cooperation and coordination state the meaning of these words in the context of this research. **Collaboration** is a coordinated social process in which two or more actors or collectives align their programs-of-action to achieve consequent goals. Interacting parties mutually presume an altruistic interest to contribute to the achievement of another's goal. For example, bees collaborate to build a beehive that hosts their offspring.

Cooperation is a coordinated social process in which two or more actors or collectives weave their discordant programs-of-action pursuing their best possible outcome. Parties in a cooperative situation have a symbiotic interaction because their successes benefit one another. For example, bees cooperate with flowers because, in the achievement of their individual goals – nutrition and pollination, respectively – each benefits from the others' actions, even though they have dissimilar goals.

Collaboration and cooperation require coordination between the interacting parties. In both forms of social interaction, it is in the best interest of the parties to coordinate because doing so maximizes the interaction efficiency. Social actors exhibit **coordination** when they mutually fulfill each other's expectations in a timely way. Coordinated action allows individuals in the group to make plans based on the given circumstances and to expect actions from others accordingly.

3.4.4.1 Degree of coordination. Based on observations of the pilot studies (reported in Chapters 4 and 5) a mode of analysis of flow of action is devised to assess the *degree of coordination* of an activity. The degree of coordination is the estimate of how much action *re-planning* is done by activity participants as they interact. An activity achieves a high degree of coordination when its actors minimize action re-planning. Conversely, an activity has a low degree of coordination when actors need to constantly adapt their programs-of-action. In other words, a good coordination between actors is achieved when their actual actions mutually fulfill each other's expectations. The result of good coordination between actors is a smooth flow of action in an activity, uninterrupted by *ad hoc* negotiations.

As an example, imagine two drivers who need to cross a very narrow bridge. Driver *A* goes from east to west, and concurrently, driver *B* goes in the opposite direction. The bridge only has room for one car at a time. The two drivers *subscribe* themselves to the bridge's program-of-action as they approach the bridge platform in their vehicles. If both drivers attempt to cross the bridge simultaneously, they will get to a point of conflict on the bridge where at least one of them will need to reverse. Neither of them will reach their destination if they stubbornly persist in their original programs-of-action. In this situation, turn-taking seems to be the only solution to the problem. But who goes first and who goes next? Axelrod's (1984) study on cooperation shows that in this kind of situation, the emergence of turn-taking coordination depends on the probability that the two actors will meet in the same situation again. This probability is called the *shadow of the future*. The degree of coordination described here assumes a null shadow of the future, that is ,that the two drivers will never meet again at the bridge.

If drivers *A* and *B* both wait simultaneously at opposite ends of the bridge, aware of one another, both have two possible options: wait until the other crosses, or go ahead and drive onto the bridge platform and get entangled in a conflict. If one driver expects the other driver to hold on until he/she crosses, and the latter driver actually holds on until the former crosses, then the actions and plans of both drivers are highly coordinated. Any other scenario yields a lower degree of coordination because either one of them, or both, will need to change their original plans to fulfill their goals. For instance, if both hold on expecting that the other will cross first and neither of them does it, then they need to iteratively re-plan what to do until they both get around the conflict. Table 3.3 shows the degrees of coordination of the drivers' interaction. This imaginary situation presents two scenarios with high degrees of coordination.

Table 3.3 Degree of coordination of drivers crossing a bridge.

Driver A	Driver B	
	Driver B holds on, expecting driver A to go	Driver B goes, expecting driver A to hold on
Driver A holds on, expecting driver B to go	Low	High
Driver A goes, expecting driver B to hold on	High	Low

3.4.5 Triadic structure of social relationships of collectives. Based on the above analysis of interactions *within* and *between* collectives, this research proposes a *triadic structure of networked social interaction*. The purpose of this triadic structure is to define an instrument for the analysis and design of mediating artifacts as networked actors. Given that the interest of this research is on computational mediators, the triadic structure is described in terms of smart artifacts, but the same model can be applied to any embodied, nonhuman mediator.

The proposed triadic structure is a simplified description of the interaction *within* and *between* collectives. The triadic structure is constituted by two individual human actors and a single smart artifact. One human actor and the smart artifact are bracketed as a collective of two actors. The interaction of these two actors corresponds to the **within interaction**. The remaining human actor represents a counterpart in the network with which the bracketed collective shares a *between interaction*. Figure 3.5 represents the foundational structure in which *H* stands for a human actor and *other* stands for the complementary human actor.

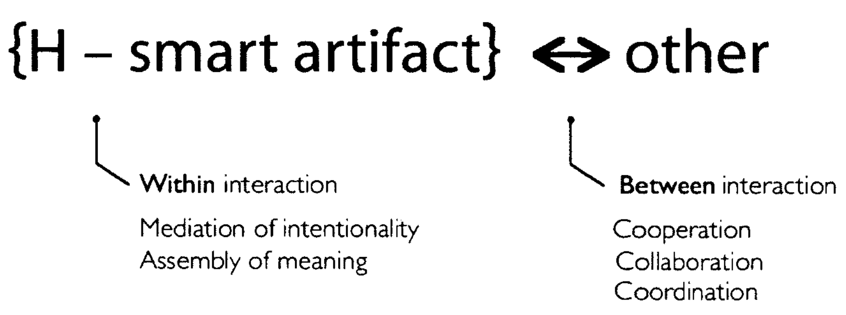


Figure 3.5 Triadic structure of networked social interaction

3.4.6 Extensions of the triadic structure of collectives to clusters of actors. The more simple version of the triadic structure, which is described above, comprises two human actors and one smart artifact. However, this structure can be extended to clusters of actors as presented in Figure 3.6. In this figure, the smart artifact constitutes a collective with a cluster of multiple human actors. This new collective acts upon a human actor *H*.

As ANT argues, the network of actors can be expanded as new actors and collectives are added, while old collectives may dissolve. Such expansion is an *AND* form of translation of programs-of-action. In some instances, the actions of two collectives with different configurations can obtain the same result, therefore they are interchangeable. This form of replacement of a collective is an *OR* form of translation.

H <-> {smart artifact – others}

Figure 3.6 Single and multi-human structural configurations

3.5 Ontology of smart artifacts as social agents

So far a smart artifact has been defined as a nonhuman mediator of interpersonal interactions with which people establish intentional relationships. In what follows an explanation of what kind of social agent is a smart artifact is offered. The explanation accounts for both, when it stands by itself, and when it is articulated within a collective.

3.5.1 Behavioral and proactive agents. All the forms of agency discussed in Chapter 2 define an agent as an embodied entity capable of performing an action. From ANT this research borrows the idea that humans and nonhumans are equivalent actors in society, yet it is important to acknowledge that their forms of action are not equal, because nonhumans lack of genuine intention. From Schultz (1972), this research borrows the distinction between types of action: behaviors and actions. Based on these categories a nonhuman actor is defined as a *behavioral agent* because it lacks of genuine intention – it cannot fantasize a desired state of affairs. It can only react to the surrounding conditions by performing scripted behaviors. Consequently, a human actor is defined as a *proactive agent* because he/she generally acts with intention and can plan a program-of-action according to a hypothesized future state of affairs. A proactive agent can also act as a behavioral agent, but a behavioral agent cannot be proactive.

3.5.2 Two types of behavioral agents: scripted and autonomous. Every behavioral agent is designed with a structure suitable to run a script. In ANT parlance, scripts are the programs-of-action of nonhumans. If either the structure or the script of a behavioral agent is fixed, then the behavioral agent is scripted – but if either of those elements is self-adaptive then the agent is autonomous.

A *scripted behavioral agent* performs only the actions its structure affords. For example, the speed hump obstructs, the car suspension dampens, the plane flies. But some artifacts can adapt their structure or their programs-of-action. For example, a plane's autopilot can autonomously adapt itself to the circumstances. Thus an *autonomous behavioral agent* can exhibit autonomy. The only purpose of its autonomy is to preserve its identity by adapting itself while acting. It cannot use its autonomy to plan a future state of affairs. Therefore, an autonomous behavioral agent, although autonomous, cannot set a goal outside the scope of possibilities in which its identity is preserved. In that sense, the autonomous behavioral agency exhibits a *weak* notion of agency (Wooldridge & Jennings, 1995). As an example, a commercial flight, put in very simple terms, is a system that involves a crew, passengers, and an aircraft. Its purpose is to safely bring passengers from point X to point Y. The plane's autopilot cannot change the current flight destination by its own will, but it can execute decisions in order to preserve the identity of the plane as a system. So, in case of an emergency, it can reroute to the safest airport in order to maintain the integrity of the crew, the passengers, and the artifact itself. Although the new destination was chosen by the autopilot, its motivation is still the preservation of the system's integrity. To clarify, this research is not interested in the *strong* notion of agency defined by Wooldridge and Jennings. Smart artifacts do not have beliefs, desires nor intentions.

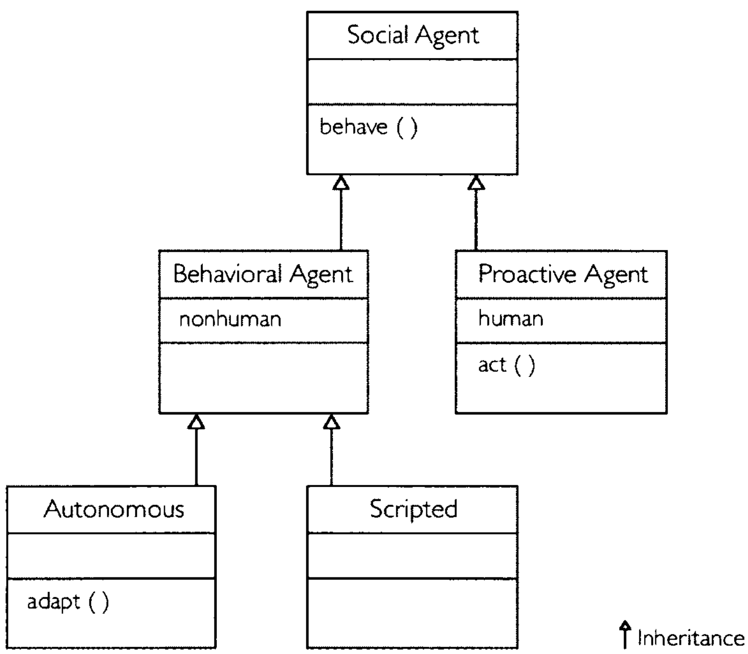


Figure 3.7 Class hierarchy of social agents

An autonomous behavioral agent elaborates an understanding of the situation in which it is involved as it experiences disturbances from other agents or from the environment. Such disturbances could lead to adaptations of the agent's organization or structure in order to preserve its stability. If those adaptations stretch out the system's organization or structure to the point that its integrity is compromised, then the agent radically avoids such disturbances. Given the fact that the behavior exhibited by the autonomous behavioral agent is a response to its environment, it is said that it makes sense of the world as the agent enacts it.

Figure 3.7 (above) shows the class structure of scripted and autonomous behavioral agents. The kind of social agent that can be instantiated by a smart artifact is an autonomous behavioral agent. The smart artifact is a nonhuman actor whose particular form of action is to adapt its structure to work in concert with the program-of-action of the host collective. Adapting its structure means to change its material configuration and attributes. In other words, the smart artifact adapts its affordances to favor or constrain collective action.

In pragmatic terms, the mediating role of a smart artifact in an activity consists of recursively i) reading the actions of actors subscribed to the activity, ii) processing and interpreting those readings based on the scripted social principles of the activity's dominant relational model, and iii) signaling suggestions or offering affordances that promote cooperation or collaboration between actors. Such mediating role ends at the moment the collective's members get unsubscribed of the artifact's program-of-action.

3.5.3 Executed and remaining program-of-action of social agents. According to Schutz, the building blocks of actions are simple acts. When we observe behavioral or proactive agents acting out their programs-of-action some of their acts are already executed, whereas others are yet to be executed. The set of executed acts is referred to as an *executed-program-of-action*, while the set of the yet-to-be-executed acts is referred to as a *remaining-program-of-action*. The remaining-program-of-action has a subjective meaning. In contrast, the executed-program-of-action has an objective meaning because it was put in front of other agents (See Fig. 3.8).

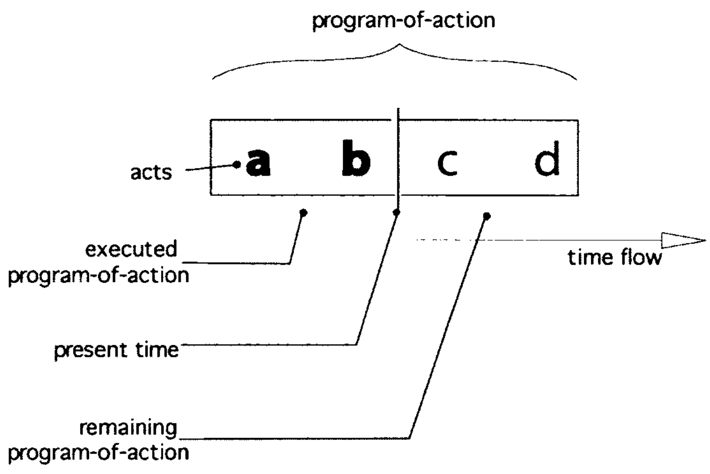


Figure 3.8 Executed and remaining program-of-action of social agents

When a human-nonhuman collective is constituted, a third program-of-action is articulated from the ones of its constituent parties, preserving the planning capacity of the human party. Therefore, the collective inherits the capacity to plan a program-of-action and fantasize a future state of affairs. If the smart artifact is socially apt, it will constantly adapt its remaining-program-of-action to better support cooperation or collaboration.

3.5.4 Scope of action of autonomous behavioral agents and action patterns. The collection of possible actions in which a smart artifact can get involved constitutes its *scope of action*. As an autonomous agent, its scope of action is constituted as its program-of-action matches any of the ongoing perceived actions.

The agent's mechanism that identifies actions in the environment is based on Schutz's formal structure for the constitution of actions and experiences. The attributes of an act are the time tag when the act was initiated, its indexicality (Suchman, 1987), in this instance its location in space, the set of agents involved, and the executed-program-of-action to which it belongs. Acts need to share akin attributes in order to be regarded as tokens of a monothetic action.

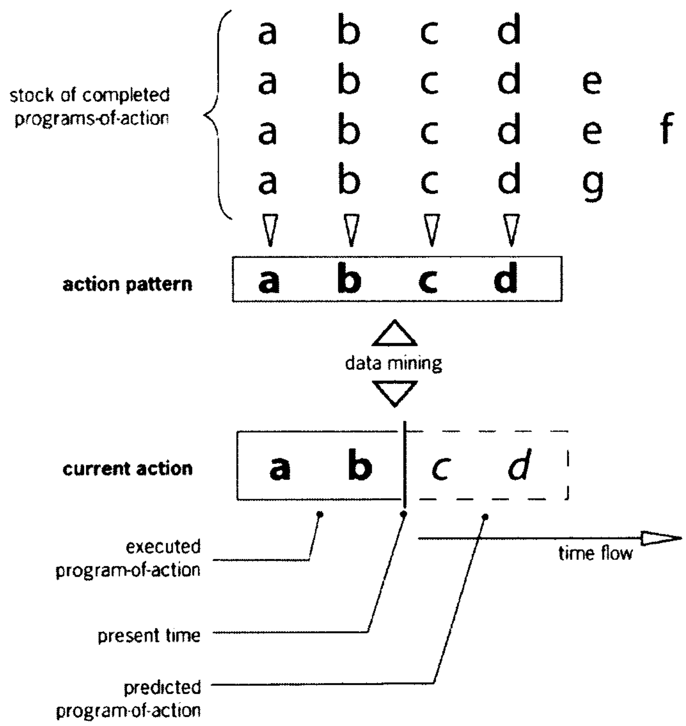


Figure 3.9 Action pattern: executed and predicted program-of-action.

An autonomous behavioral agent can only infer the meaning of executed acts if it identifies them as tokens of an agent's program-of-action. Once the autonomous behavioral agent identifies a program-of-action, it can evaluate if it is completed or not by comparing it with an *action pattern* extracted from a database of completed programs-of-action. If the program-of-action has not been completed, then the agent can predict the remaining-program-of-action and facilitate its execution.

Although the remaining-program-of-action is subjective, it can be predicted with some accuracy by analyzing the action pattern of executed-programs-of-action. Such patterns are consolidated as sequences of acts that occurred in the past.

As an example, if some people gather repeatedly at an outdoor spot, and have a box of cigarettes at hand, and then light up cigarettes with a smart lighter, an action pattern is constituted. Then, it is possible for the smart lighter to predict that someone will need it every time the circumstance recurs. Based on that prediction, it can activate its affordances. The *predicted-program-of-action* can be derived by using data mining to match the executed-program-of-action with an action pattern (See Fig. 3.9). Some data mining techniques that can be explored are: *Market-basket analysis* (Brin, Motwani, & Silverstein, 1997; Kantardzic, 2003), *Rough set theory* (Pawlak, 2003), *Hidden Markov model (Brdiczka & Reignier, 2005)* and *Apriori algorithm (Rashidi & Cook, 2009).* Conducting such exploration falls beyond the scope of this research.

3.5.5 Adaptable affordances of smart artifacts. The notion of program-of-action is applicable to the design of affordances and constraints. For ANT the program-of-action is ascribed to nonhuman actors and enacted by human actors, whereas for user-centered design (e.g. Norman & Draper, 1986) the program-of-action could be inscribed in the artifact's affordances and constraints with which the user interacts.

This research suggests that the design of smart artifacts can be enriched by rethinking affordances and constraints as mechanisms for distributed collective action. A smart artifact can adapt its affordances to facilitate or constrain social action based on the predicted-program-of-action of the collective to which it belongs. It can adapt its physical affordances to physically support social interaction, for example like granting access to someone, bringing people closer, or blocking someone's action. It can also adapt its cognitive affordances to facilitate the participants' thinking or knowing about how to cooperate or collaborate.

The design of a smart artifact's affordances for social interaction should not be viewed as a problem of usability because its main goal is not the efficiency of the system-user relationship. The real purpose of such design is the facilitation of social exchange. The design of affordances needs to be considered beyond the design of means to operate, control or manipulate the world. The physical and cognitive aspects of affordances need to be taken as signifiers of the equality-based model underlying the network of actors of which they are partakers, the potential communal effects of the artifact's operation, and the feedback about the social actions performed.

3.5.6 A model for the implementation of smart artifacts in human sociality. Figure 3.10 presents a summary of the ontology of smart artifacts and their relations with human actors in a UML class diagram. The general attributes and functions of each class are included, along with comments for each class definition.

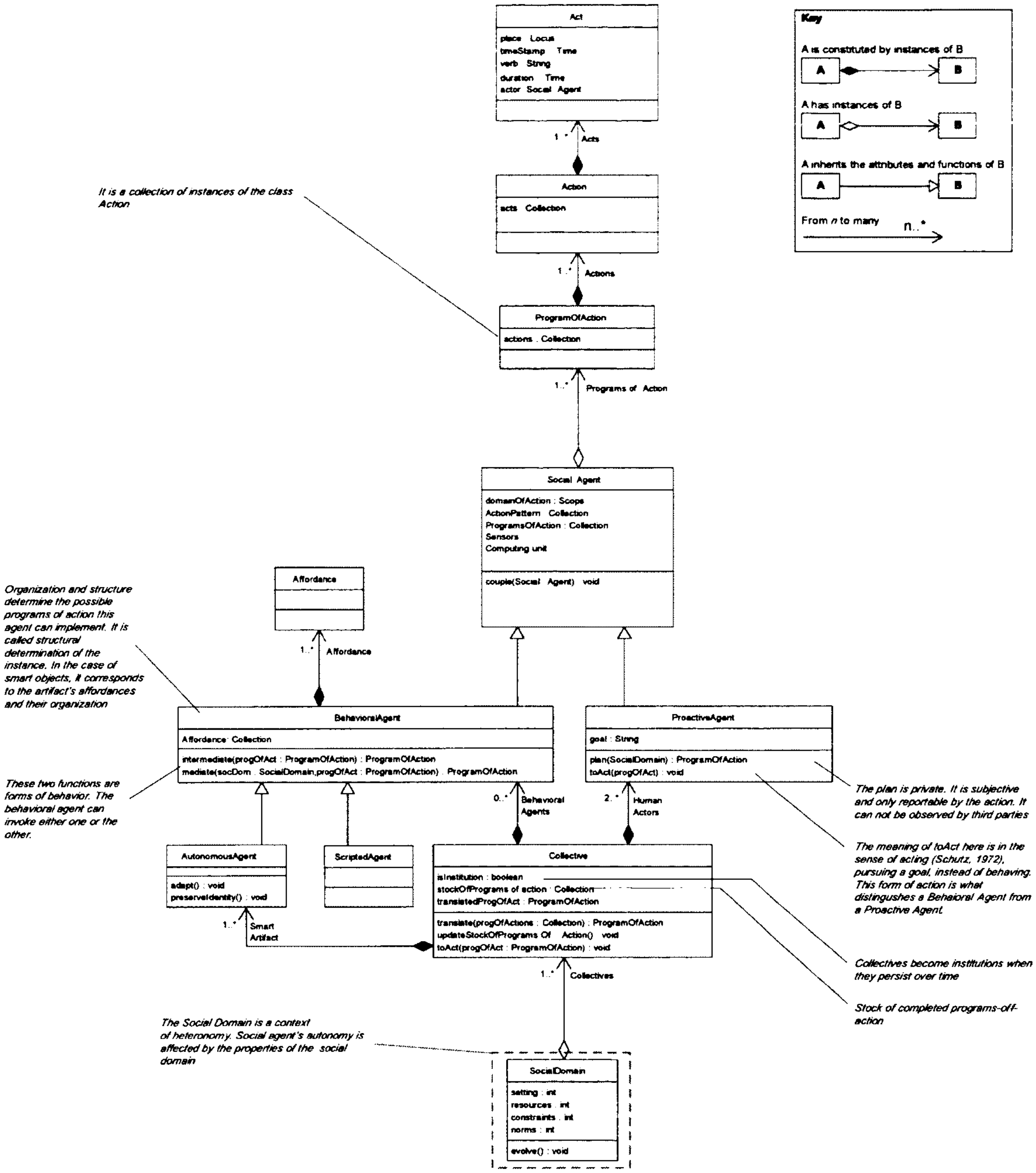


Figure 3.10 Formal structure of human-smart artifact collectives enactment in a social domain

CHAPTER 4

METHODOLOGY

As discussed in the above chapters, Schutz clearly states that while the objective meaning of an actor's action is what is interpreted by other person during the enaction of such action, the subjective meaning of that action remains in the actor's mind. There is an understanding between an actor and the interpreter of his/her actions when the actor's subjective meaning and the interpreter's objective meaning converge. In order to achieve mutual understanding between actor an interpreter, both meanings need to have a minimal match. This explanation partially accounts for one of the questions of this research: *How can smart artifacts mediate the mutual understanding of people when they interact?* But there is still a big question in regard to smart artifacts mediating such understanding. Fiske's Relational Model Theory is a solid theoretical framework for the exploration of answers to the problem of artifacts in social mediation because it characterizes interpersonal interactions based on moral principles. From the four relational models offered by Fiske, this research selects Communal sharing and Equality matching because they are based on equivalence-balanced sociality. The moral principles of such relational models can be represented by smart artifacts that display to what extent people's actions affect the balance of the activity's dominant relational model. Hence, the definition of the first focus of inquiry is fine-tuned as: *How can smart artifacts effectively signify the underlying moral principles of the dominant relational model in a network of actors?*

The second research question which inquires: *How the design of smart artifacts can promote social interaction between interrelated actors?* Collaboration and cooperation are the two types of social interaction between collectives of interest in this research. Coordination is a contingent aspect to either form of social interaction, and its degree can be assessed in order to determine the fluidity of a social activity. Therefore, this focus of inquiry is fine-tuned as: *How is the degree of coordination affected by the actions of a smart artifact*?

In order to explore these two questions, two comparative studies, namely *Study 1* and *Study 2A*, were formulated to observe how individuals coped with each other in simple activities. The design of the two studies motivated by these research concerns is twofold. First, to have one activity in which subjects were more prone to cooperate, and another one in which they were more prone to collaborate. Second, to have one study based on Communal sharing relational model, and another based on Equality matching. The activity in Study 1 was *crossing a crosswalk with other people* that aimed to study cooperation in social groups with a Communal sharing relational model. The activity selected for Study 2A was a table game consisting in *building puzzles concurrently*. This study aimed to analyze the emergence of collaboration in social groups with an Equality matching relational model. It is important to clarify that each activity's goal and rules were not explicitly outlined to urge people to one or another form of social interaction. Each activity was structured to make people interact and the intention was to observe how and when cooperation or collaboration emerged in either study.

The two studies had different instantiations of smart artifacts. The aim of each artifact was to let subjects more easily track their activities and understand them in the context of the group's activity. Each smart artifact acted out *implicit interactions* because the actions of subjects – pedestrians and game payers respectively – were not aimed at interacting with the computerized system, but it understood them as inputs that triggered one of the system's program-of-action. When a smart artifact evaluated potential conflicts between the programs-of-action of subjects, it displayed dynamic representations intended to convey the ideal equilibrium of the dominant relational model of the ongoing activity. In both studies, raw interactions – without the intervention of a smart artifact – were observed, and the results were contrasted to determine to what extent such dynamic representation, as well as other independent variables, affected cooperation or collaboration between subjects.

For Study 1 and Study 2A a first group of sixteen subjects were recruited by e-mail and social network invitations targeting the Chicago urban population. The criteria for inclusion were to be older than 18 and under 70 years old, be fluent in English and not to be color blind. This group was composed of 7 male and 9 female subjects with diverse nationalities: one from Mexico, one from China, one from Italy, two from Brazil and the remaining eleven from the United States. The subjects' age ranges from 26 and 45 years old. The design studies conducted with this group of subjects took place at IIT Institute of Design in Chicago, during March 31and April 1, 2012. The total duration of studies was 4 hours each day.

Based on the observations made of subjects in Study 2A, its research protocol was adjusted to deepen the analysis of collaborations between game players. A new study named as *Study 2B* reflected the adjustments made (described thoroughly in Section 4.4).

For Study 2B, an additional group of eight subjects were recruited opportunistically on June 10, 2012 from amongst participants in a design summer camp at IIT Institute of Design. The same criteria of inclusion was followed for the selection of this second group, composed of 5 male and 3 female subjects, all of them from the United States. The subjects' age ranged from 28 to 53 years old. The design studies conducted with this group of subjects took place at IIT Institute of Design in Chicago, during June 12 and 13, 2012. The total duration of studies was 1 hour each day.

Table 4.1 Phases of empirical research

Phase	Description
1	Video documentation sampling pedestrians in the wild
2	Development of Path Analytics© for millisecond analysis of activity
3	Elaboration of experimental study design, IRB application and approval
4	Construction of smart artifacts: smart crosswalk, smart table; staging and pilot studies
5	Recruitment of subjects; two rounds of recruitment
6	Conducted Study 1 and Study 2A with 16 subjects
7	Analysis of qualitative data (interview and audio recordings); analysis of video-recorded activities via Path Analytics; statistical analysis of activity data
8	Re-design of Study 2A. Conducted Study 2B with 8 subjects
9	Analysis of Study 2B qualitative and statistical analysis
10	Comparative analysis of data from Study 2A and Study 2B

In the three studies subjects were verbally instructed at the moment of the study, observed and video recorded during the study and interviewed selectively at the end of the study. The coordination of pedestrians in Study 1 was studies by analyzing the variances of trajectories of pedestrians using custom made software and statistical analysis. The coordination of game players in Study 2A and Study 2B was studied analyzing the distribution of resources along the evolution of the game. All the data presented and discussed in Chapters 4, 5 and 6 are from these three studies.

In order to guarantee that the rights and welfare of the human subjects studied in this research were not endangered, and that they were exposed to minimal risks, the informed consent and study protocols of the study described in this chapter were approved by IIT's Institutional Review Board on January 17, 2012 (see Appendix A). Instructions and studies information were given only when subjects were present at the lab. They were clearly informed about the aim of the study, their rights and commitments before they signed the informed consent.

4.1 Units of analysis

The *triadic structure of social relationships of collectives* discussed in Chapter 3 defines the units of analysis in this study. This triadic structure accounts for the basic unit of mediated interaction in a network of actors. Subject actions in the collected sets of data were analyzed according to the *within* and *between interaction* of triadic collectives.

4.2 Study 1. Effects on pedestrian trajectory of a smart crosswalk's representation of Communal sharing symmetry

The activity analyzed in this study was crossing a crosswalk with other people. This activity was selected because crosswalks are natural places for nonverbal social interaction where people exhibit a high degree of coordination. No additional rules, other than walking from point A to point B, were necessary.

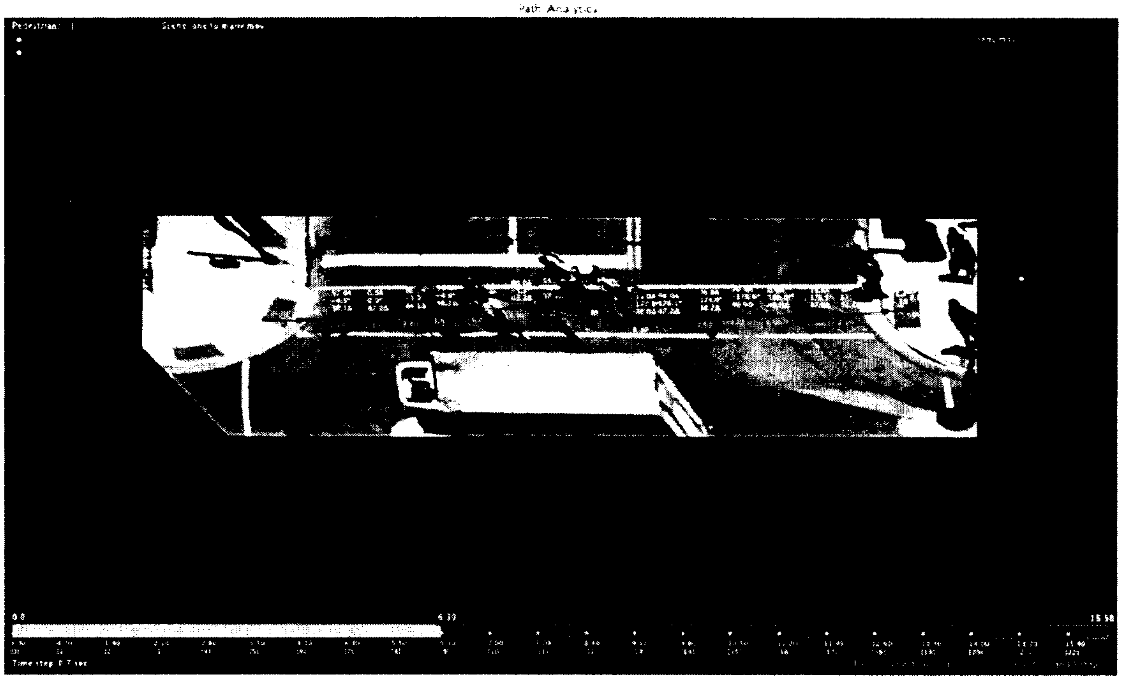


Figure 4.1 Path Analytics screenshot. Example of visualization of pedestrian trajectories

The methodology for investigation was to observe people crossing streets *in the wild*. Next, the activity was re-created in the lab along with the addition of a smart crosswalk which dynamically prompted the ideal distribution of space for the pedestrians on the crosswalk (See Table 4.2). The study's final goal was to compare the results of mediated to unmediated in-lab observations and to infer the extent to which the smart crosswalk affected the pedestrians' interaction.

4.2.1 Observation in the wild. Observations in the wild was made during lunch hours at the intersection of North LaSalle Street and Kinzie Street in Chicago, in the summer of 2011. This downtown neighborhood has an active crowd of business people during weekdays, specially between 11:45 and 2:00 pm. Specifically, pedestrians were observed and video recorded pedestrians crossing the east crosswalk on Kinzie Street.

Table 4.2 Summary of Study 1: Effect of the display of Communal sharing symmetry by a smart crosswalk on pedestrian trajectories

	Study question	
Study aspect	How can smart artifacts effectively signify the underlying moral principles of the dominant relational model in a network of actors?	To what extent is the degree of cooperation or collaboration of an activity improved by the actions of a smart artifact?
Activity	·Crossing a crosswalk with other people	·Crossing a crosswalk with other people
Independent variables	·Number of pedestrians on the crosswalk ·Type of signaling enacted by the crosswalk ·Full or limited visual perception	·Number of pedestrians on the crosswalk ·Type of signaling enacted by the crosswalk ·Full or limited visual perception
Dependent variables	·Enrollment to activity ·Pedestrian variation of trajectory ·Degree of coordination	·Enrollment to activity ·Pedestrian variation of trajectory ·Degree of coordination ·Subscription to the activity
Sources of evidence	·Direct observation, video recording, joystick recorders and post-observation interviews	·Correlation of post-observation interviews and video footage
Type of data collected	·Video and audio recordings ·Quantitative data of each pedestrian intended trajectory collected via the joystick recorder.	·Video and audio recordings ·Interviews
Form of analysis	·Correlation between observed behavior of pedestrians walking on smart crosswalk signaling modes ·Statistical analysis of joystick recorders data	·Correlations between dependent and independent variables based on data collected by Path Analytics ·Statistical analysis of degrees of coordination

Six representative configurations of pedestrian collectives were found in the analysis of the sample from Kinzie street. People tend to walk individually or in groups of up to three individuals. Therefore, people cross paths in six possible configurations: i) 1 coming vs. 1 going , ii) 1 coming vs. 2 going , iii) 1 coming vs. 3 going, iv) 2 coming vs. 2 going, v) 2 coming vs. 3 going, and vi) 3 coming vs. 3 going (this was rarely observed). Larger groups are possible but they tend to fragment into sets of maximum three people. These *configurations of pedestrian collectives* define the fundamental distribution of space on a crosswalk. Such distribution constitutes the design principle for representing Communal Sharing symmetry on a smart crosswalk in the laboratory studies (See Table 4.3).

Table 4.3 Distribution of a crosswalk width based on the configuration of pedestrian collectives

No of pedestrians coming	No of pedestrians going		
	1	2	3
1	$\frac{1}{2}+\frac{1}{2}$	$\frac{1}{3}+\frac{2}{3}$	$\frac{1}{4}+\frac{3}{4}$
2	-	$\frac{1}{2}+\frac{1}{2}$	$\frac{2}{5}+\frac{3}{5}$
3	-	-	$\frac{1}{2}+\frac{1}{2}$

For the analysis of pedestrians' trajectories a custom-made software named *Path Analytics©* was developed. Path Analytics is a video analysis tool that assists the tracking of subjects' motion in video footage, and in computing their degrees of coordination. In order to analyze trajectories, video files of recorded path-based activity of interest were uploaded into the software Path Analytics. Next, each footage of the naturally occurring activities of pedestrians was split into even segments at a predefined temporal unit of resolution in milliseconds. The software retrieves the first frame of each segment and presents them on a timeline of *cover frames*. At that point, each subject is manually pinned down cover frame by cover frame, generating a series of *path nodes*. Once the path nodes are pinned down, the software generated three main outputs per subject on the footage: i) a visualization of each subject's trajectory during the recording (See Fig. 4.1), ii) a dataset containing each path node's time stamp, course, displacement, and disturbance from the expected trajectory, and iii) a second dataset containing the subject's executed and predicted program-of-action, and his/her potential zones of conflict (See Fig. 4.2).

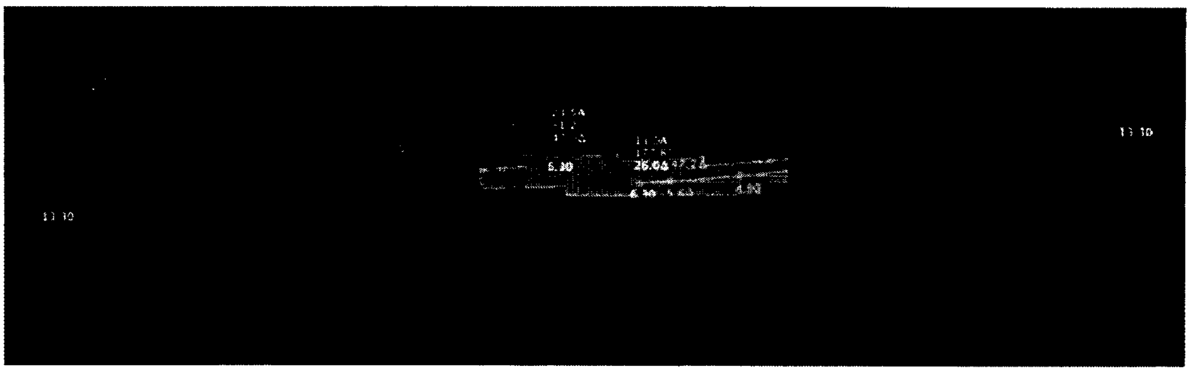


Figure 4.2 Analysis of two pedestrians crossing paths made in Path Analytics. The dotted lines correspond to their executed-programs-of-action. Each node displays its timestamp, relative position, direction and deviation. The bright area at the center presents the zone of potential conflict derived from the predicted-programs-of-action. The colored areas on the sides present the estimated zone of action of each pedestrian

4.2.2 Lab re-creation, design intervention and independent variables. The smart crosswalk deployed in the lab was designed as a dynamic zebra pattern which varied its symmetry as subjects walked on top of it. The pattern symmetry changed according to the distribution of the configuration of pedestrians described in Table 4.3. Two *signaling modes* were tested in this study: the smart crosswalk detected and *highlighted* potential zones of conflict between pedestrians (See Fig. 4.3), or the smart crosswalk detected a potential zone of conflict and *suggested* a direction to get around it (See Fig. 4.4).

The recreation of the crosswalk in the lab was instantiated as a carpet of 18.25 m of length and 1.89 m of width, which demarked the walking area. On top of it, a Wizard of Oz prototype of the smart crosswalk was deployed (Dahlbäck, Jönsson, & Ahrenberg, 1993).

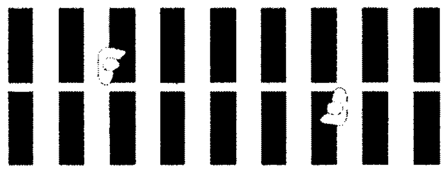


Figure 4.3 Smart crosswalk highlighting signaling modes displaying a ½ + ½ symmetry

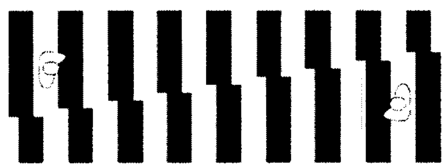


Figure 4.4 Smart crosswalk suggesting signaling modes displaying a ½ + ½ symmetry

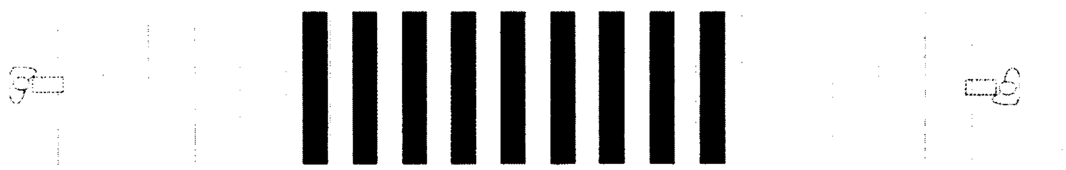


Figure 4.5 Smart crosswalk neutral position

One variation of subject's visual perception limited by completely dark glasses was also tested. The underlying idea was that people struggle to coordinate in information-scarce environments. Therefore, in some runs of the study, the visual perception of subjects was limited to just few feet ahead, preventing them from planning their trajectories. This limitation reveals how much participants relied on the information presented by the smart crosswalk.

Three independent variables were controlled in this study: i) the configuration of pedestrians on the crosswalk, ii) the smart crosswalk signaling mode, and iii) the subject's visual perception range.

Figure 4.6 Pedestrians with limited perception

4.2.3 Sources of evidence and types of data collected. The sources of evidence were direct observation, video recording, path tracking devices and post-observation interviews. Subjects in the lab were video recorded by five cameras (See Fig. 4.7). Three cameras were located on top of the smart crosswalk to capture a bird's-eye view of the subject trajectories. The remaining two captured the perspective from the north and south ends of the carpet.

Figure 4.7 Camera views of the smart crosswalk deployed in the lab

In addition, the subjects entered their intended trajectories in hand-held joystick recording devices (See Fig. 4.8). The purpose of these devices was to capture intended or imperceptible changes of trajectory that were not evident in video recordings. The intended trajectory is the direction people would like to go, but it is not necessarily the direction they exhibit because they may divert as they recognize potential conflicts ahead. These devices were joystick controllers that recorded two variables in a single data point: direction and time. The direction variable took three possible values: left, neutral or right. The time variable was the elapsed time since the moment the subject stepped on the carpet. At the end of the study participants were interviewed collectively.

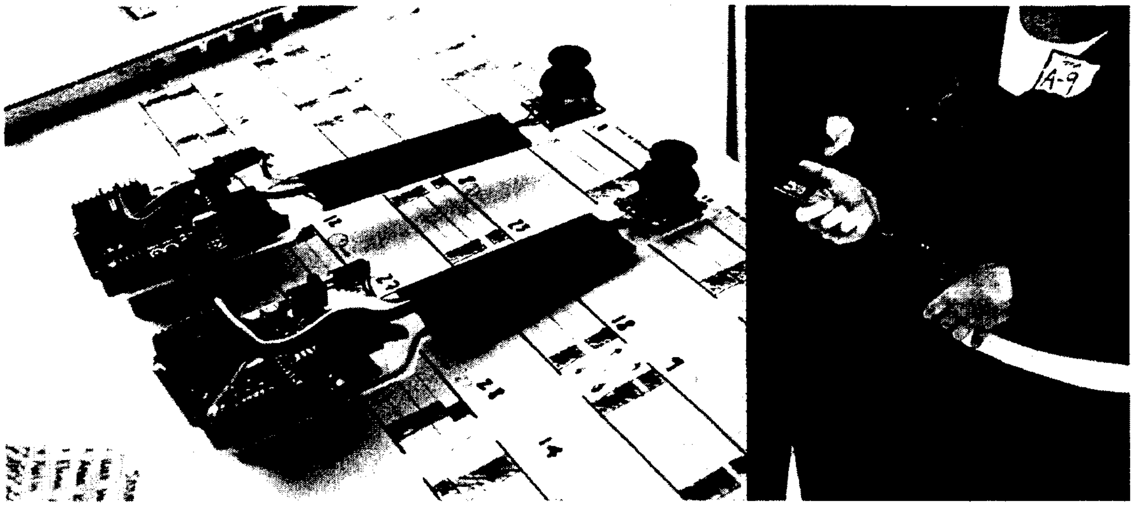


Figure 4.8 Hand-held device for self recording trajectory

4.2.4 Procedure. Sixteen subjects from a pool of volunteers took part in this study. They were distributed in two groups of eight people, and each group was invited in the lab on separate weekends. The lab had one waiting room where participants waited until they were called to a separate room, named *the stage*. The smart crosswalk was deployed at the staging room. The procedure was arranged in 20 runs (5 configurations of pedestrian collectives, times 2 crosswalk signaling modes, times 2 subject visual ranges). At the beginning of each run a facilitator called a subset of up to five randomly-selected subjects to the stage. Each subject – now acting as a pedestrian – got a joystick recording device and was assigned to one of the two ends of the carpet (north or south). Next, the two pedestrians or collectives of pedestrians located on opposite sides of the crosswalk were asked to walk from one end of the corridor to the other, and to stop when they crossed the final line.

Table 4.4 Arrangement of study runs and their relation to the independent variables tested in the crosswalk study

Crosswalk signaling mode	Full visual perception	Limited visual perception
Highlighting	1 vs. 1	1 vs. 1
	1 vs. 2	1 vs. 2
	1 vs. 3	1 vs. 3
	2 vs. 2	2 vs. 2
	2 vs. 3	2 vs. 3
	N = 18 pedestrians	N = 18 pedestrians
Suggesting	1 vs. 1	1 vs. 1
	1 vs. 2	1 vs. 2
	1 vs. 3	1 vs. 3
	2 vs. 2	2 vs. 2
	2 vs. 3	2 vs. 3
	N = 18 pedestrians	N = 18 pedestrians

Table 4.4 presents four arrangements of study runs: i) crosswalk in highlighting mode with full perception, ii) crosswalk in highlighting mode with limited perception, iii) crosswalk in suggesting mode with full perception, iv) crosswalk in suggesting mode with limited perception. Each arrangement had five runs following the number of configuration of pedestrian collectives.

4.2.5 Dependent variables and modes of analysis. The dependant variables observed were the pedestrians' speed, target deviation, and the degree of coordination represented in their trajectory disturbance.

Walking speed is easily calculated by observing the elapsed time pedestrians took to traverse the smart crosswalk. Their *target deviation* is calculated in reference to their intended target. The intended target is the pedestrian's projected target at the far end of the crosswalk. For example, lets us imagine that a crosswalk goes from two sidewalk corners along the north-south axis. If one pedestrian starts walking on the north-east end of the crosswalk, the intended – and expected – target is the south-east end of the crosswalk. It is likely that he/she may encounter disturbances along the crosswalk, and be forced to divert his/her trajectory. As a result, the pedestrian might have a target deviation from the intended target (See Fig. 4.9).

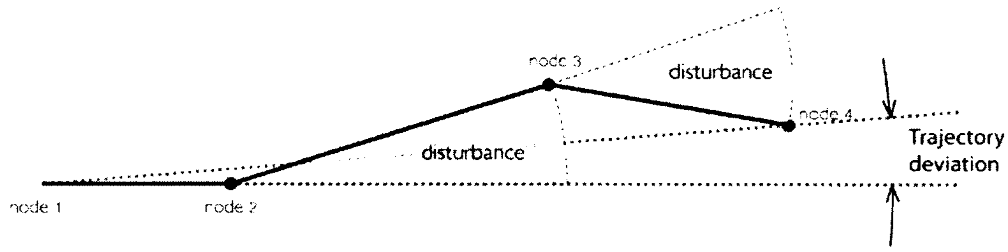


Figure 4.9 Target deviation

The degree of coordination is the amount of program-of-action re-planning done by activity participants while they interact (See Chapter 3). A good coordination between actors is achieved when they mutually fulfill each others' expectations. In the case of crossing a street, such expectations are: i) have a straight corridor, clear of other pedestrians, so one does not bump into someone else, and ii) keep a close proximity between one's self and one's companions. In order to assess the degree of coordination of pedestrians in a crosswalk, Path Analytics provided a measurement of deviation of each pedestrian from the program-of-action of the crosswalk. The program-of-action of the crosswalk is to demarcate a rectangular walking area in which pedestrians are intended to walk straight from corner to corner.

The trajectory of each pedestrian was traced in the software, resulting in a chain of path nodes connected by geometric vectors. The vector magnitudes represent the pedestrians displacement between two nodes in pixels, and the vector angles represent their discrete courses. A *disturbance* in the path is the change in the magnitude or the trajectory course between two consecutive vectors. The size of the disturbance is the result of adding the square of the vectors' magnitude difference, plus the area of an arc whose radius corresponds to the magnitude of the latter vector, and its angle to the supplementary angle between the two vectors (See Fig. 4.10). This angle is referred to as *course deviation*.

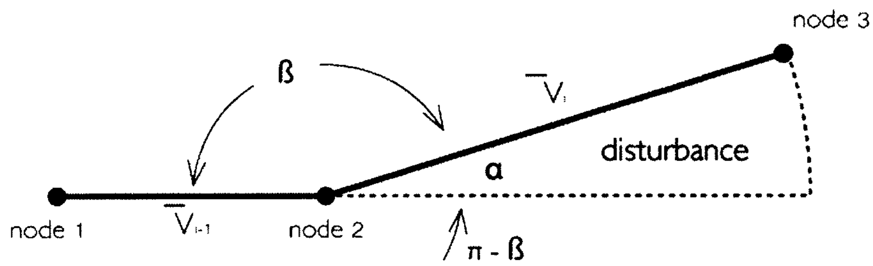


Figure 4.10 Disturbance of pedestrian trajectory

The *trajectory disturbance* of a pedestrian is the average of all the individual disturbances in his/her trajectory path (See Equation 1).

Equation 1 Trajectory disturbance (TD) of a pedestrian, where n is the total number of disturbances, V is the magnitude of the current vector, and α is the supplementary angle between the current and the previous vectors.

$$TD = \frac{1}{n}\sum\nolimits_{i=2}^{n}(V_i - V_{i-1})^2 + (\tfrac{1}{2}V_i^2\alpha)$$

After the observed activities of pedestrian trajectories and interaction (that were video-recorded), the comments made by subjects in the post-hoc collective interview (that were also video recorded) were correlated with the analysis of trajectory observations. In addition to the modes of analysis described above, and in order to find statistically significant evidence of the differences between the effects of the two smart crosswalk signaling modes, the following statistical analysis of the trajectory deviation were conducted: First, a chi-square (X^2) test of the categorical dataset collected with joystick recorders to evaluation the differences between the frequencies of trajectory changes. Second, a series of t-tests and one-way ANOVA of the quantitative data derived from Path Analytics results to evaluate the difference between the sample means. These are presented in Chapter 5.

4.3 Study 2A. Effect of a smart table's representation of Equality matching symmetry on game players

The aim of this study was to learn at what point in an activity subjects were motivated to collaborate while they each individually pursued the same tasks. The assumption was that individuals within a concurrent Equality matching activity were not prone to collaborate with others even though they were sharing resources. As mentioned above, the activity examined in this study was a table game in which players *concurrently build individual replicas of a building block puzzle*. In order to provoke collaboration, this study introduced two conditions: First, a shared pool of scarce resources from which subjects needed to draw blocks; and second, a smart table on top of which players built their puzzles while it prompted them with their progress, and with any imbalance in the distribution of pieces.

Table 4.5 Summary of Study 2A: Effect of the display of Equality matching symmetry by a smart table on game players

	Study question	
Study aspect	How can smart artifacts effectively signify the underlying moral principles of the dominant relational model in a network of actors?	To what extent is the degree of cooperation or collaboration of an activity improved by the actions of a smart artifact?
Activity	·Concurrently building individual Lego puzzles	·Concurrently building individual Lego puzzles
Independent variables	·Information displayed on the table	·Information displayed on the table
Dependent variables	·Number and time of communications among subjects ·Duration of activity per table	·Number of suggestions and negotiations among subjects ·Duration of activity
Sources of evidence	·Direct observation ·Video recording ·Post observation interview	·Direct observation ·Video recording ·Post observation interview
Type of data collected	·Video and audio recording	·Video and audio recording
Form of analysis	·Quantitative insight finding ·Correlation of interview answers with observed actions	·Quantification of observed actions ·Correlation of interview answers with observed actions

4.3.1 Puzzle design and smart artifact intervention. Subjects, randomly arranged in groups of four, were assigned a smart table and a common pool of blocks. The pool of blocks barely had enough pieces to build four replicas of a reference puzzle. The reference puzzle was a simple model purposely designed to be built with only two possible combinations of pieces (See Fig. 4.11). One combination used 7 long blocks plus 2 short blocks, whereas the other used 8 long blocks. The pool of resources had the exact amount of pieces to build four models per table following the 7+2 combination, i.e., 28 long and 8 short blocks. If one subject used more than 7 long or 2 short blocks, then someone else at the table was not able to complete the puzzle because the pool balance was broken.

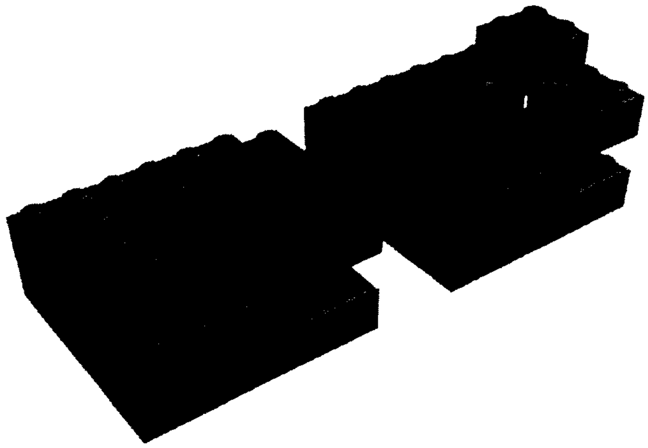


Figure 4.11 Two instances of the puzzle model to be replicated by subjects. The one on the left shows one way of building the model with 8 long blocks. The one on the right shows another way of building the model with 7 long and 2 short blocks

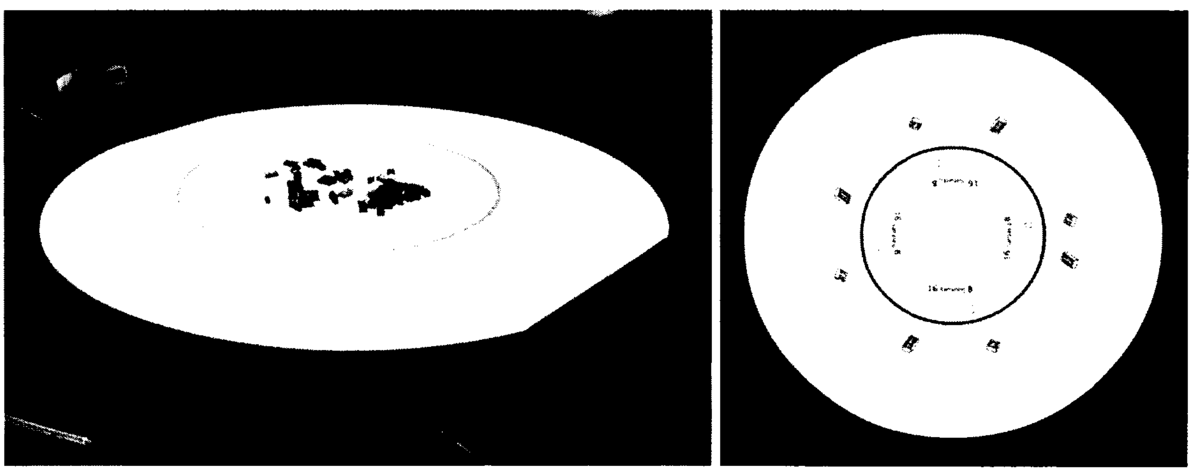


Figure 4.12 Smart table of Study 2A. Top view of the table interface (right)

The smart artifact in this study was a round smart table that displayed numerical information about the status of individual progress and group resources depletion. The smart table counted how many blocks were used in each puzzle, and calculated the remaining blocks in the pool (See Fig 4.12). By displaying this information, subjects were informed about the distribution of blocks among their puzzles. The smart table was a Wizard of Oz prototype (Dahlbäck, *et al.*, 1993) which simulated the actual behavior of a smart table.

4.3.2 Study variables. The independent variable controlled in the study was the information displayed on the table. The dependent variables observed were: i) the length of time spent by each players during his/her moves, ii) the sequence and number of pieces used by each player, and iii) the moment when subjects verbalized suggestions or negotiations to others. The move duration indicated a player's struggle during a move. If the player spent significantly more time in his/her turn than the average duration, that indicate that he/she was engaged in a demanding mental processing. This variable is not robust enough by itself, however it provides a reasonable indicia of the player's cognitive demand. The sequence and number of pieces indicated how resources were distributed as the game evolved and therefore facilitated the computation and study of imbalances of the hypothesized Equality matching model of the game. Finally, verbal suggestions were evident signs of social interaction.

4.3.3 Study procedure. Sixteen subjects took part in this study. To simplify the logistics, they were distributed in two study days, eight subjects per day. Subjects, arranged in two groups of four people, were assigned to two smart tables, but the groups were not defined as teams. Each subject was equally entitled to draw one block from the pool per turn. Subjects had their own accountable goal, identical to each other's, that is, to build the model. The criterion of success was to build a solid puzzle that replicates the shape and color of the original model. The game rules were explained verbally, and it was emphasized that the game had no scores and that it was not a competition. It was clearly stated that finishing first was not the aim of the game and that there were no prizes if they succeed.

To start the activity, each subject, now acting as a player, drew three long blocks from the pool of resources. This initial three blocks are the *puzzle seeds* from where players started the construction of their puzzles. Turn order was left for players to negotiate among themselves. The reason why the game was turn-based was to facilitate data collection and to give enough time for the research assistant to operate the prototype. Then, to complete their own replicas, the players drew one block per turn from the pool of blocks scattered on the smart table. The visual interface of the smart table was not explained in advance. This study's interest was partially into observing if the information presented by the table was self explanatory. The smart table counted how many blocks were used by each player, calculated the number of remaining blocks, and displayed the count for each individual on top of the table. The game had no time restriction, and ended when all the players at the table completed their puzzles. An open-ended round of questions and answers about the activity was conducted and video-recorded afterwards.

4.3.4 Data collection. The methods for data collection were note taking from direct observation, video/audio recording of the procedure, and post-experiment interviews that were video/audio recorded.

4.4 Study 2B. Building puzzle replicas in teams

As described above, subjects in the analysis of Study 2A worked concurrently with other people but each player was responsible for a single puzzle. In an early analysis of Study 2A results, it was clear that players only cooperated at the very end of the game and that the smart table was not useful in the process of cooperation or coordination. Two months later, a second smart table study – Study 2B – was conducted with eight new subjects. The smart table was redesigned and the game rules were modified to encourage more cooperative or collaborative behavior among subjects (See Fig. 4.13). The pilot runs of this study showed that the number of puzzles to be built by the team must not be divisible by the number of subjects in the team because the subjects assumed that they were responsible only for a fraction of the goal, preventing collaborative or cooperative interaction. Therefore, in Study 2B, subjects were assigned to teams of two, each responsible for three puzzles.

As in Study 2A, the criterion of success was to build a solid puzzle that replicated the shape and color of the same model. Rules were explained verbally, and emphasis was placed on the non-competitive spirit of the game. It was clearly stated that finishing first was not the aim of the game and that there were no special rewards if the team succeed.

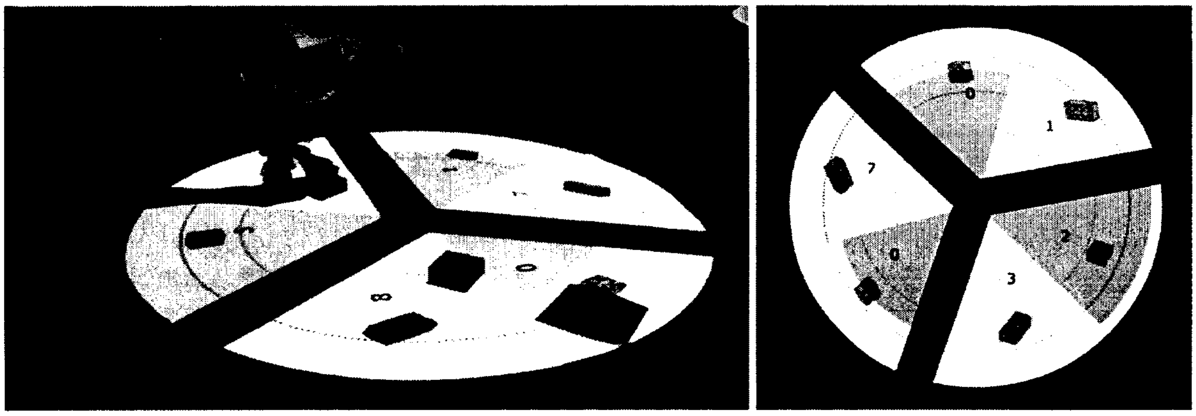


Figure 4.13 New smart table interface of Study 2B. Top view of the interface (right)

Table 4.6 Summary of Study 2B: Effect of symmetry displayed by a smart table on game players

Study aspect	Study question	
	How can smart artifacts effectively signify the underlying moral principles of the dominant relational model in a network of actors?	To what extent is the degree of cooperation or collaboration of an activity improved by the actions of a smart artifact?
Activity	·Concurrently building collective Lego puzzles	·Concurrently building collective Lego puzzles
Independent variables	·Whether information is displayed on the table	·Whether information is displayed on the table
Dependent variables	·Number of turns used ·Number of pieces moved back from the building to the resources table	·Number of turns used ·Number of pieces moved back from the building to the resources table
Sources of evidence	·Direct observation ·Video recording ·Post observation interview	·Direct observation ·Video recording ·Post observation interview
Form of analysis	·Qualitative insight finding ·Correlation of interview answers with observed actions	·Quantification of observed actions ·Correlation of interview answers with observed actions

The final goal of Study 2B was to compare the two teams, of which one did the task at a smart table. The puzzles were the same as in Study 2A, but in this version the smart table on the surface prompted the ideal distribution of puzzle pieces as proportional areas of color instead of digits. Study 2B was not interested in observing when negotiations were elicited. Instead the evolution of coordination between team players without verbal communication was observed.

4.4.1 Procedure. Eight subjects, now acting as players, took take part in this study. To simplify the logistics, they were distributed in two days, four players per day. On each of the two days, the players were paired in two teams. After that moment the players were not allowed to communicate verbally. This prevented them from sharing plans, developing leadership, or instructing each other as they drew pieces from the pool. The teams were asked to build three identical puzzles. Each team was responsible for the completion of all three puzzles, and none of the players had previous information about the puzzle model. The players took part in the study only once, therefore the Equality matching relational model of the game was preserved because they did not have the chance to develop hierarchical positions within each teams.

Each team was assigned two round tables set 2 meters apart - the *resources table* and the *building table*. The building table of one of the teams was a smart table with the new visual interface. Team members took turns drawing pieces from the resources table, brought them to the building table, and added them to one of the three models. No leftover pieces could remain on the building table and the members could not be at the same table simultaneously.

Under these conditions, players of both team members always had out-of-date information about the game activity. On the one hand, the player drawing pieces from the resources table did not know what would be the puzzles' status back at the building table. On the other hand, the player at the building table did not know what would be the best distribution of his/her own pieces in order to match the future pieces brought to the building table. The assumption was that their optimal strategy would be to build the puzzles in parallel so they preserve the balance of pieces among the puzzles.

4.4.2 Smart artifact intervention. The new design intervention divided the table into three equal pie-slice-shaped areas, one per model to be built, each with two sub-slices differentiated by color. The slices presented the same data as the previous smart table, but this time in graphical proportions that represented the balanced or unbalanced distribution of resources used for the three puzzles. By displaying with digits the total number of pieces of the kind used in each puzzle, the smart table reinforced the total number of pieces employed in each puzzle.

4.4.3 Study variables. The independent variable of the study was the same as in Study 2A, i.e., the information displayed on the smart table. But the dependent variables observed in this new version of Study 2 were the number of turns used to complete the task, and the distribution of blocks between the three puzzles.

CHAPTER 5

RESULTS AND DATA ANALYSIS

5.1 Results of Study 1. Effect of Communal sharing symmetry representation by a smart crosswalk on pedestrian trajectories

Sixteen adult volunteers randomly assigned to groups of up to four people were asked to walk on a smart crosswalk. The groups followed four out of six configurations of pedestrian collectives. The configurations 2 vs. 3 and 3 vs. 3 were left out due to time constraints. The smart crosswalk enacted two signaling modes: highlighting (H) or suggesting (S). The subjects' field of visual perception had two ranges: full (FP) and limited (LP). As a result, this study had 16 runs, i.e., 4 configurations of pedestrians multiplied by 2 crosswalk signaling modes, and by 2 visual perception fields. The study yielded four pairs of datasets collected under each field of visual perception (See Table 5.1). Each pair contains one dataset of categorical data of the intended direction of pedestrians and a second dataset of quantitative data containing the speed, target deviation and trajectory disturbance of pedestrians.

Table 5.1 Four datasets collected under four study conditions

Signaling mode	Visual perception field	
	Full	Limited
Highlighting	FP-H: categorical and quantitative datasets	LP-H: categorical and quantitative datasets
Suggesting	FP-S: categorical and quantitative datasets	LP-S: categorical and quantitative datasets

5.1.1 Smart crosswalk effect on pedestrian intended trajectories: Analysis of categorical datasets. In an examination of how many times pedestrians intended to divert their trajectories as they walked along a smart crosswalk, pedestrians were arranged in the described configurations and were asked to record their intended direction using a hand-held recording device. A *pulse* value of 1 was recorded every time a pedestrian pushed the device's joystick to the left, and a value of -1 was recorded when he/she pushed it to the right. The set of pulses entered per participant, per run, is named as a pedestrian's *deviation set*. At the end of the each run, each pedestrian delivered two deviation sets, one with the aggregation of left pulses and another one with the aggregation of right pulses (See Fig. 5.1). If both deviation sets had no entries, they were consolidated in a single void deviation set, indicating that there was no trajectory change. The lower the number of pulses in a deviation set, the more stable the pedestrian's trajectory.

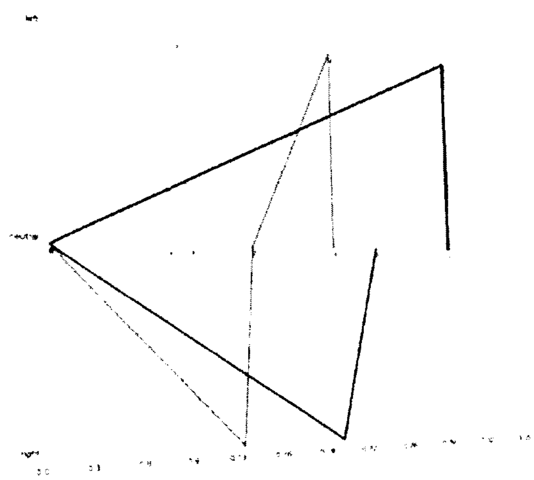


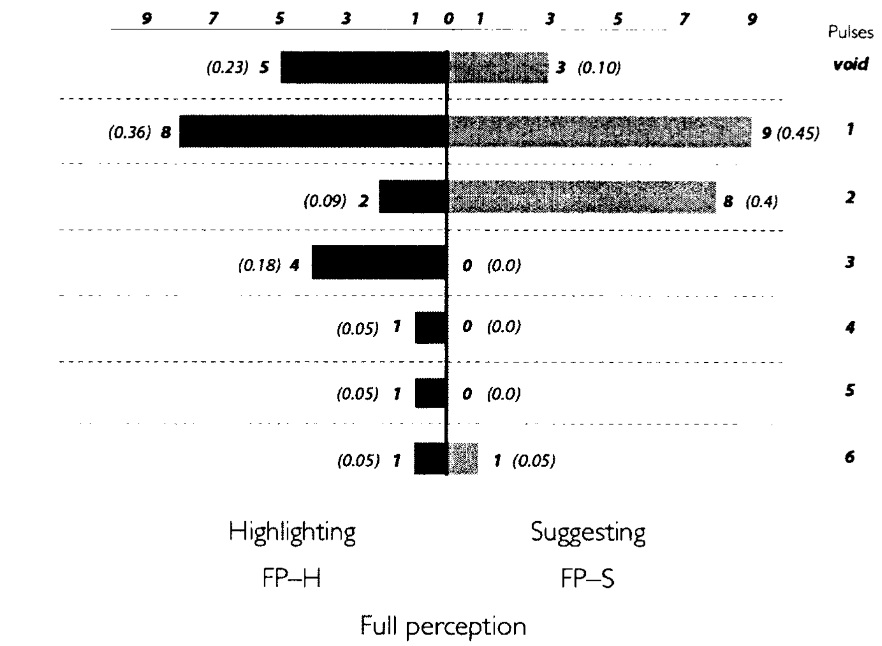
Figure 5.1 Example of a time series chart of four pedestrians' deviation sets

Table 5.2 presents the deviation sets under each study condition and sorted by their number of pulses. It shows that the total number of deviations under each condition, as well as their averages are fairly similar. As observed in a back-to-back frequency distribution (See Fig. 5.2), the four clusters of deviation sets are positively skewed. This means that, even though pedestrians tended to maintain a stable trajectory, on average they diverted a similar amount of times regardless of the study combined condition. In general terms, it is possible to assert that a pedestrian changed his/her trajectory once, twice or none of the time when he/she walked on a smart crosswalk.

Table 5.2 Deviation sets of intended direction of pedestrians

Pulses per set	Study Condition			
	FP-H	FP-S	LP-H	LP-S
void	5	2	3	3
1	8	9	11	8
2	2	8	7	8
3	4	0	3	1
4	1	0	0	1
5	1	0	0	1
6	1	1	0	0
Total	22	20	24	22
Average	3.14	2.86	3.43	3.14
SD	2.67	3.93	4.20	3.44

The probability distribution of deviation sets with full visual perception (See italics in Figure 5-2) shows that, under suggesting conditions (FP-S), the chance of entering more than two pulses in a run is negligible; whereas in highlighting conditions (FP-H), it is slightly higher. A switched distribution of probabilities between highlighting and suggesting modes is observed in limited perception datasets. Pedestrians in limited perception and suggesting conditions (LP-S) had a slightly higher chance of entering more than three pulses than in highlighting conditions (LP-H).



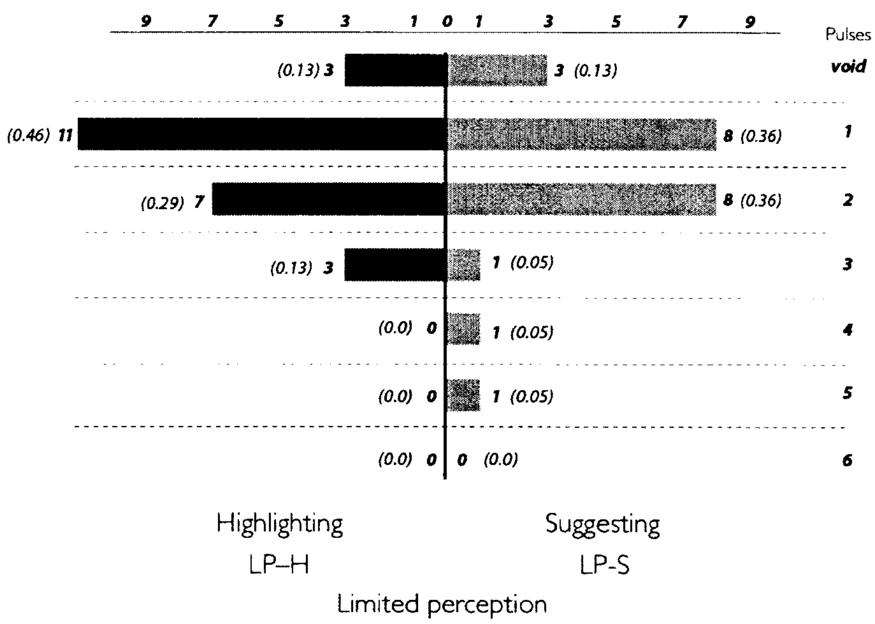


Figure 5.2 Frequency distribution of deviation sets of pedestrians and their probability distribution

The difference of standard deviation of highlighting and suggesting datasets collected under each visual perception condition (FP-H - FP-S = 1.20 and LP-H - LP-S = 0.76) indicates that it is likely that the effect of a smart crosswalk highlighting potential conflicts is not the same as when it suggests course changes to pedestrians. In order to test whether the difference is statistically significant or not, two Chi-square (X^2) tests were conducted. One with the datasets of pedestrians with full perception (FP-H and FP-S), and one with the datasets of limited perception (LP-H and LP-S). The former study produced $X^2 = 10.87$ on 6 degrees of freedom, which is statistically significant at $p < 0.1$. The latter study produced $X^2 = 3.45$ on 6 degrees of freedom, which is not statistically significant at $p < 0.1$.

As a conclusion, it appears that pedestrians entered a similar number of pulses in either visual field condition. Another conclusion is that pedestrians with full visual perception take trajectories significantly more steadily when a smart crosswalk suggested (FP-S) trajectories rather than when it highlighted (FP-H) potential conflicts. As to pedestrians with limited visual perception, there is not conclusive evidence that their trajectories are impacted in one way or the other, whether the crosswalk either suggests trajectories or highlights potential conflicts.

5.1.2 Smart crosswalk effect on the disturbance of pedestrian trajectories: Analysis of quantitative datasets. In addition to the datasets described in the introduction to this chapter, data from two control runs of configuration 1 vs. 2 were collected. One with in full visual perception (FP-Control), another in limited visual perception (LP-Control). Both control runs had no intervention of the smart crosswalk.

Tables 5.3 to 5.8 presents a summary of the average walking speed, average target deviation, and average trajectory disturbance of subjects.

Table 5.3 Dataset of pedestrians in full perception and highlighting mode (FP-H)

Configuration	Runs	N	Avg. speed	Avg. target deviation	Avg. Disturbance
1 vs. 1	2	4	78.74	2.81	93.42
1 vs. 2	2	6	73.33	2.87	80.41
1 vs. 3	2	8	74.14	2.46	67.42
2 vs. 2	2	8	68.61	4.20	99.87
Average			73.70	3.08	85.28

Table 5.4 Dataset of pedestrians in full perception and suggesting mode (FP-S)

Configuration	Runs	N	Avg. speed	Avg. target deviation	Avg. Disturbance
1 vs. 1	2	4	71.97	5.05	107.71
1 vs. 2	1	3	64.94	3.37	87.10
1 vs. 3	1	4	75.13	2.79	106.78
2 vs. 2	1	4	68.71	4.64	96.72
Average			70.19	3.96	99.58

Table 5.5 Dataset of pedestrians in limited perception and highlighting mode (LP-H)

Configuration	Runs	N	Avg. speed	Avg. target deviation	Avg. Disturbance
1 vs. 1	2	4	73.70	3.33	90.32
1 vs. 2	1	3	63.43	2.74	51.64
1 vs. 3	1	4	55.78	5.96	71.38
2 vs. 2	2	8	56.49	4.54	75.33
Average			62.35	4.14	72.17

Table 5.6 Dataset of pedestrians in limited perception and suggesting mode (LP-S)

Configuration	Runs	N	Avg. speed	Avg. target deviation	Avg. Disturbance
1 vs. 1	2	4	75.55	2.96	88.65
1 vs. 2	2	6	50.12	5.13	49.23
1 vs. 3	1	4	46.43	4.75	47.77
2 vs. 2	2	4	46.60	4.37	41.69
Average			54.68	4.30	56.84

Table 5.7 Dataset of pedestrians in full perception with no smart crosswalk effect (FP-Control)

Configuration	Runs	N	Avg. speed	Avg. target deviation	Avg. Disturbance
1 vs. 2	2	6	86.51	2.12	106.59

Table 5.8 Dataset of pedestrians in limited perception with no smart crosswalk effect (LP-Control)

Configuration	Runs	N	Avg. speed	Avg. target deviation	Avg. Disturbance
1 vs. 2	1	3	62.69	9.50	103.15

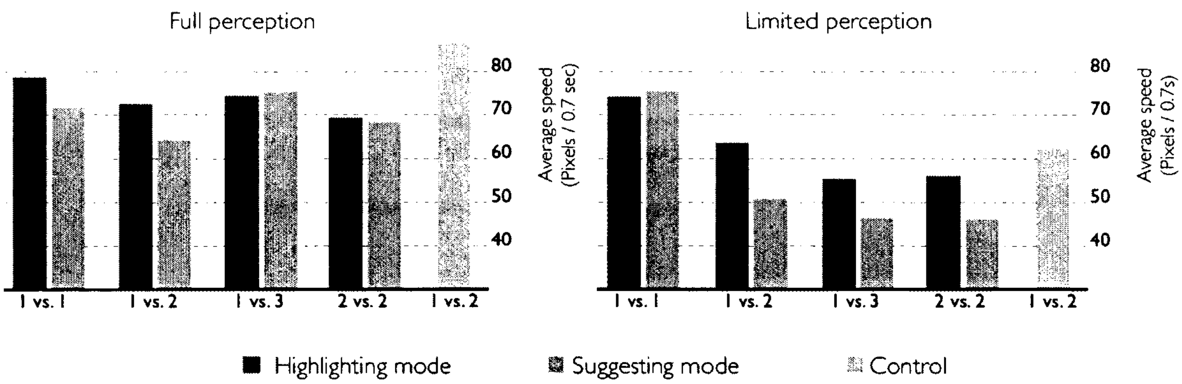


Figure 5.3 Distribution of averaged speed per smart crosswalk signaling mode

In terms of **walking speed**, the results are not surprising. The fastest walkers are those in the control group under full perception condition (FP-Control). The slowest speed is exhibited by the most crowded configuration in limited perception and suggesting conditions. Visual field and group size appear to impact walking speed. The shorter the visual perception field, the slowest the walking velocity. The larger the number of pedestrians in a run, the slower their speed. As per the impact of the smart crosswalk signals on speed, full perception datasets show that walkers in highlighting mode go 5% faster than in suggesting mode. Limited perception datasets show that walkers' velocity in highlighting conditions is 14% faster than in suggesting conditions (See Fig. 5.3).

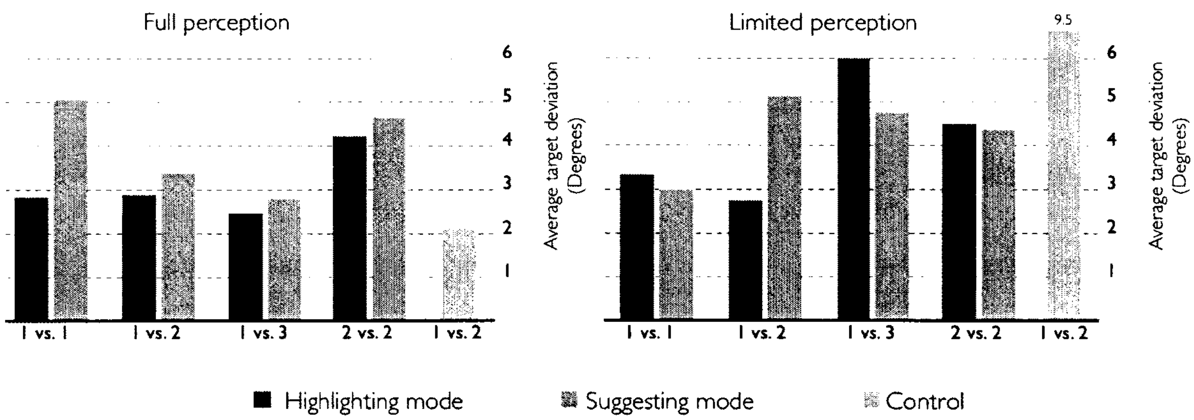


Figure 5.4 Distribution of averaged target deviation of pedestrians per smart crosswalk signaling mode

In terms of **target deviation**, pedestrian trajectories exhibited the lowest degree of target deviation when participants walked with full perception and no crosswalk intervention (FP-Control). Conversely, the highest degree of target deviation was achieved when pedestrians walked with limited perception and no crosswalk intervention (LP-Control). Hence, it is possible to infer that the reduction of pedestrians' visual perception yields target deviations. As to the impact of the smart crosswalk signals, pedestrians' target deviation was lower in highlighting conditions than in suggesting ones

(28% difference in full perception and 4.9% in limited perception). Figure 5-4 shows that target deviation tends to be higher when the configuration of pedestrians walking on the smart crosswalk is more crowded.

In terms of **trajectory disturbance**, the data show intriguing results. Pedestrians in both control datasets exhibited the highest averaged trajectory disturbance. As to pedestrians' visual perception, there is a clear difference between trajectory disturbances in full and limited perception. Trajectories of walkers in the limited perception condition had a lower disturbance than those with full perception, regardless of the crosswalk signaling mode.

As for the impact of the smart crosswalk signals, pedestrians' trajectory disturbance is switched. In full perception condition, the trajectory disturbance was 16% higher in suggesting mode than in highlighting mode. In limited perception, the trajectory disturbance was 27% higher in highlighting mode than in suggesting mode.

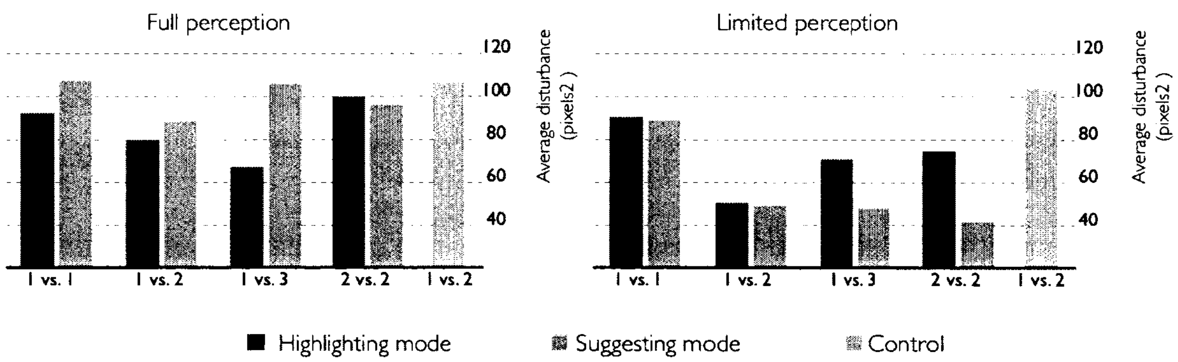


Figure 5.5 Distribution of averaged trajectory disturbance of pedestrians per smart crosswalk signaling mode.

For the most part (see Fig. 5.6), pedestrians walking on smart crosswalks slowed down their speed regardless of the smart crosswalk mode, their trajectory disturbance was attenuated, and their target deviation decreased. It appears that, in full perception condition, a smaller target deviation is correlated with a swifter flow especially in crowded crosswalks. As for the results in limited perception conditions, walking speed tended to slow down. Trajectory disturbances, as well as target deviation in both crosswalk modes were dramatically reduced.

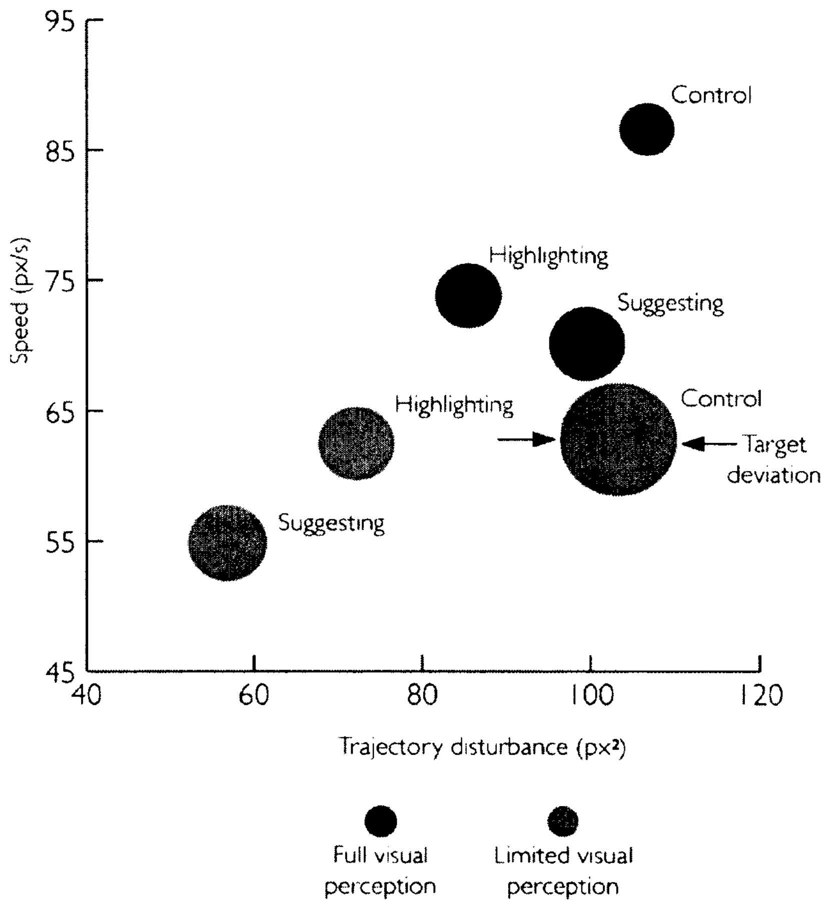


Figure 5.6 Averaged speed, target deviation and trajectory disturbance of full and limited perception datasets

The most conclusive observation is that every smart crosswalk intervention affected pedestrians' speed, target, and trajectory disturbance compared to the control datasets in either full or limited perception. None of the proposed interventions improved the walking speed of pedestrians, but both crosswalk signals lessen their trajectory disturbance. Apart from the control groups, walkers tended to flow slower in the limited perception condition combined with the suggesting crosswalk mode, and larger groups. Conversely, they tended to flow more swiftly in the full perception condition combined with highlighting mode, and in smaller groups.

In order to test the statistical significance of the effect of smart crosswalk modes on pedestrians' trajectories disturbance, eight one-tailed *t* tests were conducted, one for each pair of runs. It turns out that none of the tests were statistically significant except for the configuration 1 vs. 3 in full perception condition. The mean disturbance difference was 26.10 pixels^2 , with a standard deviation of 14.7. This test was statistically significant ($t(206) = 1.95$, $p < .05$), revealing that, on average, pedestrians in 1 vs. 3 configuration, with full visual perception, have higher trajectory disturbances in a suggesting crosswalk than in a highlighting crosswalk.

The results from this statistical analysis contradicted the researcher's qualitative observations. The researcher's perception during the recording sessions and during the data processing with Path Analytics was that in several runs, pedestrians trajectories were very disturbed, specially when they had limited perception. It was also the researcher's impression that there were major differences between highlighting and suggesting crosswalk modes. In order to better understand the *between interaction* of pedestrians the specific impact of each crosswalk signal was investigated independently. Therefore, eight statistical tests were run to evaluate the difference between the trajectory disturbance of pedestrians walking in each direction of the crosswalk per each configuration. The tests were organized in two tiers of four tests each. The four tests in tier 1, were t-tests that examined datasets of pedestrians walking in opposite direction (north to south and south to north). Whereas the four tests in tier 2, were a combination of t-tests and one way ANOVA that examined datasets of pedestrians walking in the same direction. As shown in Figure 5.7, t-tests are identified with an *a* and one way ANOVA with a *b*.

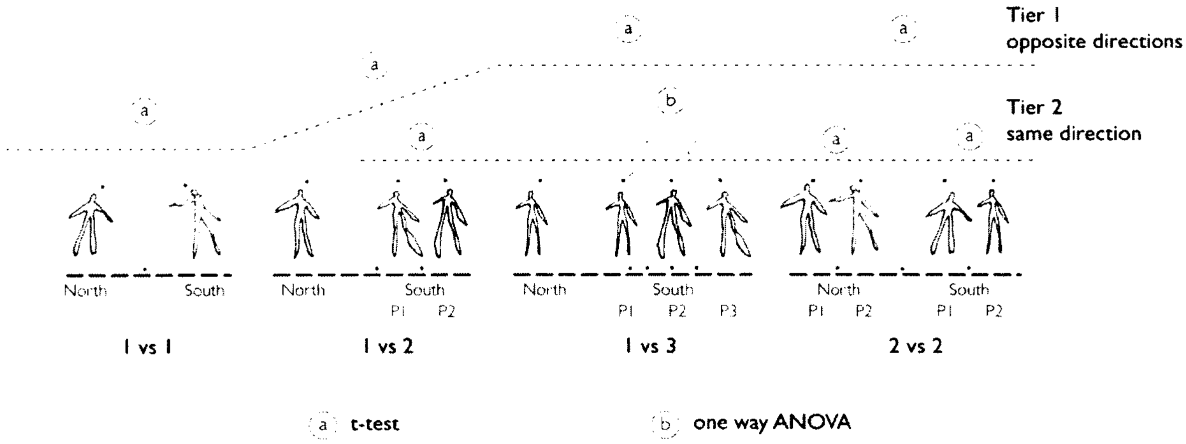


Figure 5.7 Types of statistical tests analyzing trajectory disturbance between pedestrians walking in each direction of the smart crosswalk

The results of this new set of studies revealed novel aspects of the distribution of trajectory disturbances between the two walking parties. One of the two parties walking in opposite direction usually has a remarkably higher trajectory disturbance than the other. In order to assess how much variation exists from the average trajectory disturbance of both parties (the average represents a balanced distribution of disturbances), The standard deviation of parties' means of disturbances was calculated for each configuration (See Table 5.9). The majority of results showed high standard deviations, and seven out of sixteen tier 1 tests were statistically significant. Hence, it is possible to assert that one of the walking parties on a smart crosswalk usually makes a higher effort to maintain his/her trajectory flow than the other[9].

Table 5.9 Standard deviation of parties' mean of trajectory disturbances when they walk in opposite direction. Tier 1 tests. * Statistically significant differences

Configuration	FP-H-T1	FP-S-T1	LP-H-T1	LP-S-T1
1 vs. 1	2.8	47.0*	25.4	19.7
1 vs. 2	49.4*	43.5*	16.0	13.0*
1 vs. 3	19.7	20.5	44.9*	37.6*
2 vs. 2	26.7	26.6	46.6*	5.5

Table 5.10 Standard deviation of parties' mean of trajectory disturbances when they walk in the same direction. Tier 2 tests. * Statistically significant differences

Configuration	FP-H-T2	FP-S-T2	LP-H-T2	LP-S-T2
1 vs. 2	14.1	3.3	13.6	24.0*
1 vs. 3	12.6	24.6	8.5	28.9*
2 vs. 2 north	1.1	60.2*	23.1*	4.2
2 vs. 2 south	58.6*	12.7	6.9	2.4

As for the trajectory disturbance between members of the same party, studies of tier 2 (See Table 5.10) showed that, again, one of the pedestrians needed to bend his/her intended trajectory more than the others. Five out of sixteen tier 2 test results showed statistically significant differences between trajectory disturbances of members of the same group. It seems that in order to alleviate potential jams between pedestrians, there is always someone who sacrifices his/her performance, acting as a safety valve, allowing the others to maintain their course.

[9] This is very similar to the coordination problem of drivers crossing a bridge described in Chapter 3.

The natural final question is which pedestrian in a configuration is usually the safety valve? Full and limited perception conditions offer different answers. In full visual perception, it was observed that in tier 1 tests that the larger party yields the right of way when the crosswalk highlights conflicts. But the opposite was observed in suggesting mode. In limited visual perception, tier 1 test the observations were not consistent. A qualitative analysis of video recordings and analysis of post-study interviews confirmed the observation in full visual perception, and also revealed that within a party of 2 or more pedestrians walking in the same direction (tier 2 tests), those walking in the middle of the crosswalk are more prone to bend their trajectory than those walking on the sides.

5.2 Results of Study 2A. Effect of Equality matching symmetry representation by a smart table on game players

This study examines at what point in an activity subjects are motivated to cooperate while they pursue the same tasks. Sixteen subjects – now acting as players – were randomly distributed in four groups and assigned to four smart tables. They were verbally asked to concurrently build individual replicas of a building block puzzle while the smart table prompted them with their progress, and with any imbalance in the distribution of pieces.

Unfortunately, during one of the sessions there were technical problems with one of the video recorders and it was not possible to collect data from one of the four smart tables. The results showed that cooperation did not occur in all tables, and even when it did, it occurred only at the very end of the game when players saw their counterparts struggling to solve their puzzles. The games lasted for 7 rounds with an averaged total duration of 6:35 min. Only during the very last round players started to talk about how to help the ones at risk of failing the task.

Table 5.11 Summary of the final statistics of the building block game

Game statistic	Smart Table		
	1	2	3
Game duration	6:12 min	7:56 min	5:49 min
Round of cooperation	-	7	7
Player A completion round	5	6	6
Player B completion round	6	6	5
Player C completion round	7	7	7
Player D completion round	6	7	6
Mode of number of rounds	6	6 or 7	6
Max turn duration	98 sec	257 sec	194 sec
Average of turn duration	13.29 sec	17.14 sec	12.57 sec
Mode of turn duration	9 sec	3 sec	3 sec
SD of turn duration	20.81	49.13	36.24

Verbal communication was rather scarce at the tables. However, there was a constant flow of information among the players. Information of the game progress was conveyed in i) each puzzle status, ii) the duration of each turn, and iii) the status of the pool of blocks. The puzzle status signified how far a player was from his/her goal. The duration of the turn conveyed how much re-planning was being done by a player while he/she accommodated a new block. Usually a long turn duration was regarded by researchers as a struggle. Whereas the puzzle status and turn duration conveyed information about individual status of players, the status of the pool conveyed the condition of the whole group. Figure 5.8 presents a visualization of the evolution of these three sources of information at Smart table 3, which is representative of all the observed smart tables.

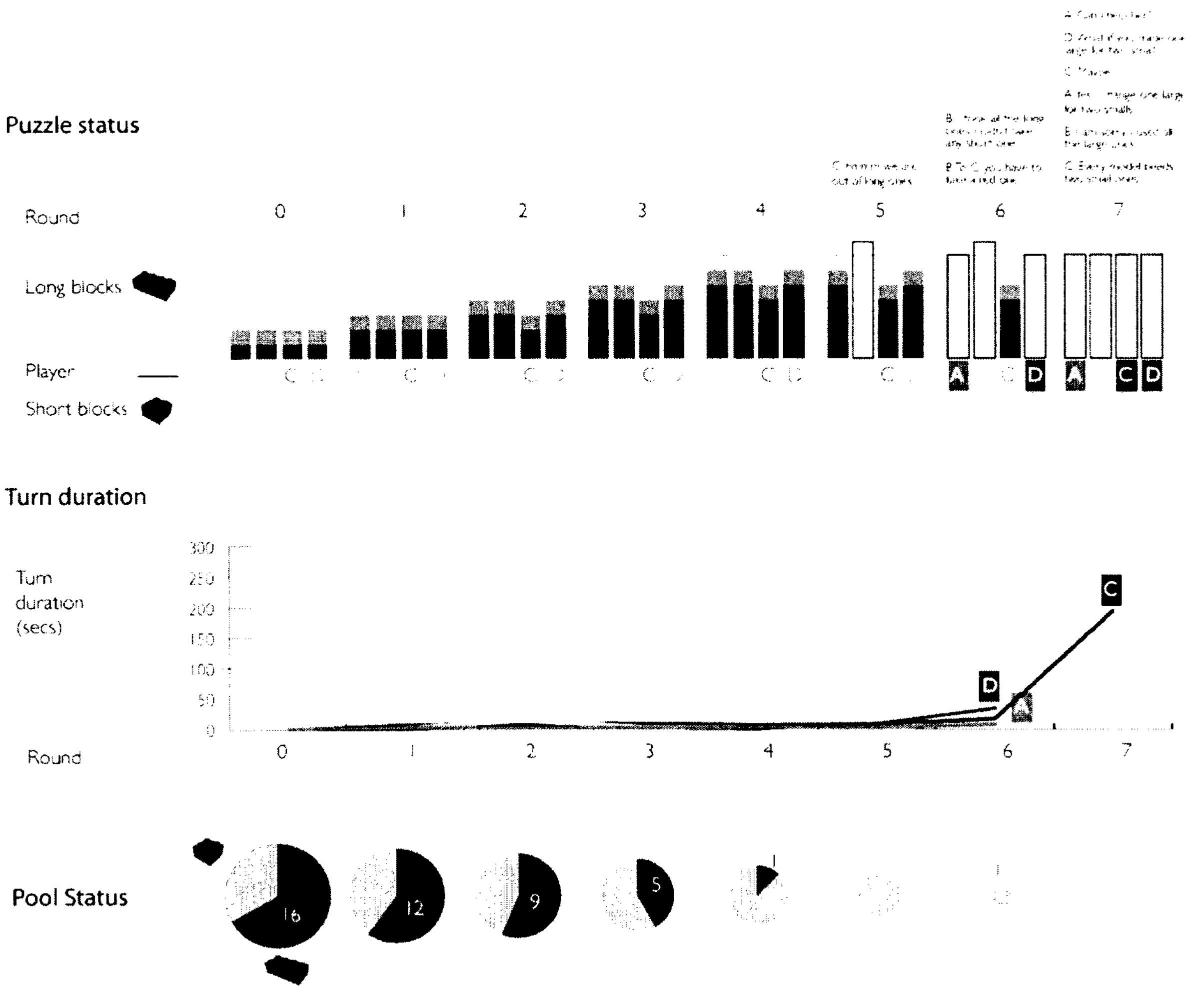


Figure 5.8 Game evolution of Smart table 3 over rounds. A,B,C,D correspond to one of the four players at the smart table. The letters with solid background means that the player completed his/her puzzle

In the top section of Figure 5.8, the puzzle status is represented as bars of squares showing the usage of blocks by players named A,B,C and D. Top bars represent the long building blocks and bottom bars the short building blocks. The distribution of resources at smart table 3 had relatively balanced progress up until round 4. In round 5, player *B* completed his puzzle using only long blocks, impeding someone from completing his/her puzzle. At that point, one of the players realized the depletion of long blocks and exclaimed: "hmmm, we are out of long ones". In round 6, players *A* and *D* completed their puzzles with the ideal distribution of pieces (7 long + 2 short). In the same turn, player *C* needed one long block but because the pool ran out of them, she was forced to draw a short one increasing her puzzle imbalance. In round 7, turn duration of player *C* increased dramatically (See middle chart of Figure 5.8). In her turn, all the players took part and contributed to find a solution to her puzzle. Player *D* suggested to *B* and *C*: "why don't you trade one large for two small?". Player *A* seconded player's *D* suggestion and after they traded their blocks, player *B* apologetically said: "I am sorry, I used all the long ones", and player *C* confirmed: "every model needs two small ones".

The assumption formulated in the study design regarding the low expectation of observing cooperation between players, even though they share the same pool of resources (See Chapter 4), seems to be true for the vast majority of game rounds except for the last round. As expected, cooperation was triggered by resource scarcity, which resulted in trading the blocks. Unexpectedly, there was a trade mediator who suggested trade operations between the player with the unsolved puzzle and other players. This is perhaps due to the fact that the mediator was a player who had completed his/her puzzle, and whose cognitive attention was not focused on his/her goal any more. Although the smart table was signaling the same conflicting imbalance pointed out by the human mediator, it appears that the table did not have major effect on the players. A possible explanation is that the table was not making any trading suggestions. In the post-session interview, participants said that they did not understand the information presented by the table, and that they barely paid attention to the digits displayed on its surface.

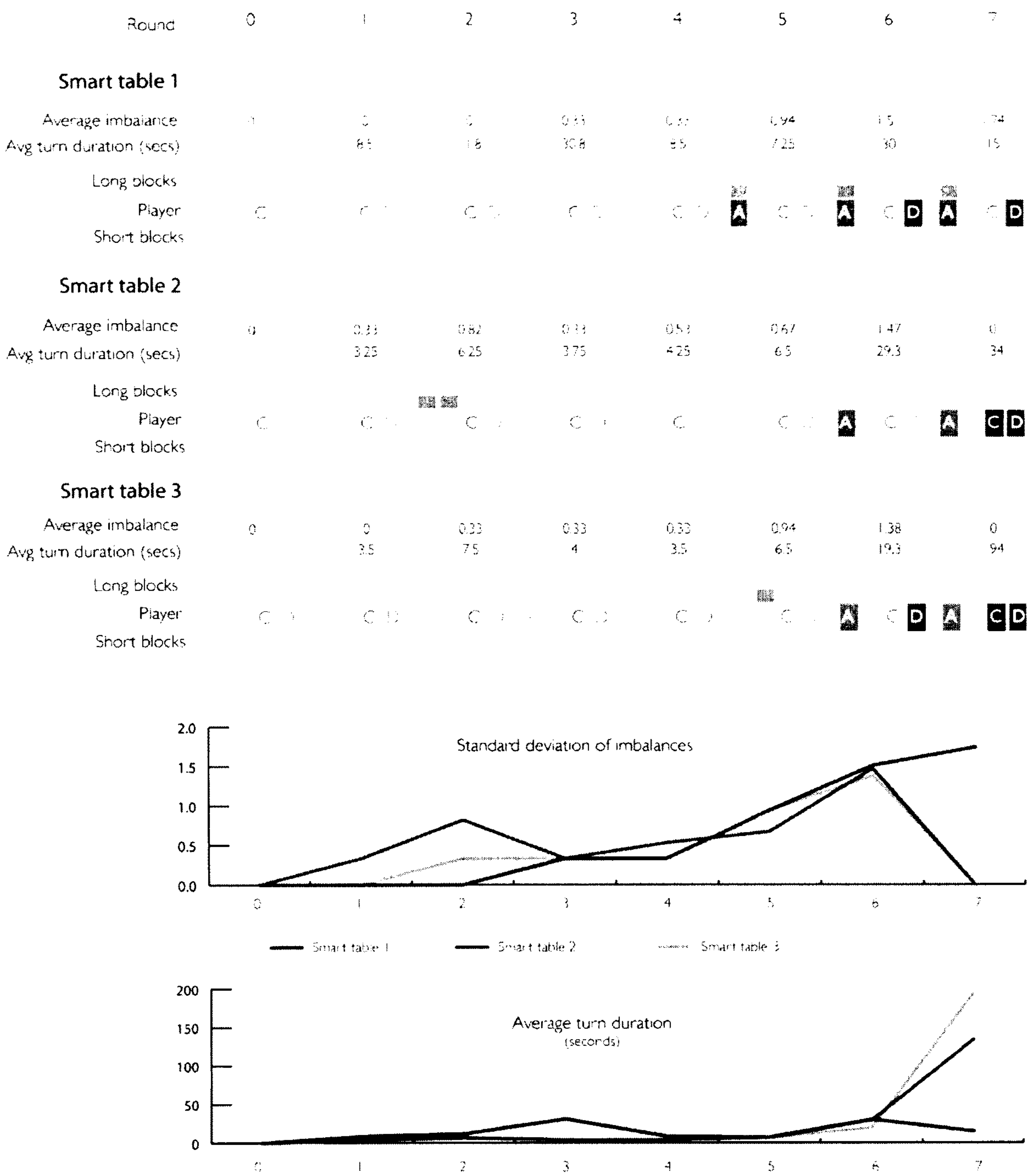


Figure 5.9 Evolution of imbalances of building blocks and turn duration at smart tables

A balanced distribution of blocks is defined as consistent if the imbalance of long and short blocks among the puzzles remains within an acceptable *imbalance threshold* during the game. A calculation of the imbalance is made by averaging the standard deviation of the distribution of long blocks and short blocks among the puzzles. A discussion of imbalance threshold will be introduced in the Chapter 6.

Figure 5.9 presents a detailed analysis of the evolution of building block distribution. This figure shows how the imbalance of building block distribution across the puzzles tended to increase as the game evolved. It reached its highest value at the penultimate round, and dropped to zero at the last round, when all the puzzles were completed. The smart table 1 was an exception because its players did not cooperate at all during the game.

Figure 5.9 also shows the change of turn duration across game rounds. The average turn duration had a tendency to last slightly longer as the game evolved. At the very last round, turn duration suddenly exhibited a dramatic increase due to players cooperation and block trading.

Turn order affected puzzle completion. The first two players always completed their puzzles before the last round, whereas one of the last two players always did it in the last round. Players with the first or second turn had earlier access to the pool of resources which benefited their performance. The longest turn always belonged to a player in the third or fourth turn at all four tables.

As per the degree of coordination of game players, the design of the game impeded the observation of coordination between players because they played in turns. Turn-taking hampered reciprocity because turns moved to the right from one player to the next, i.e., players' moves did not directly affect the move of the preceding player. Nevertheless, the collected dataset provided evidence of the degree of coordination between the pool of blocks, the player and its puzzle by measuring the duration of player's turn. It is assumed that players defined their programs-of-action using either long or short blocks. Due to the fact that they could draw only one piece per turn, the possibilities of changing their choice at the moment of picking a piece were one in two. The assumption is that a player had no disturbances in his/her turn as long as the pool of blocks offered him/her possibilities to draw his/her intended block. Therefore the turn duration is supposed to last shorter when his/her expectations are fulfilled. Conversely, the turn can last longer when he/she needs to re-plan during his/her turn. It is important to clarify that turn duration is not an accurate estimate of coordination because players can take longer turns due to problems of spatial reasoning. But, it provides evidence of the pool-player-puzzle coordination during his/her turn.

The observations of players playing in the first turn, who are the ones with higher chances of finding more abundant blocks at the pool, show that they completed their puzzles first, in shorter turns, and usually with eight long blocks. This confirms their smoother flow of action and their better pool-player-puzzle coordination during the process.

Turn duration kept steady round after round. It increased 3.5 times at the penultimate turn, and rocketed 7.5 times at the very last round. As a conclusion, players saw no major disturbances as long as they have possibilities to draw pieces from the pool. The shrinkage of resources affects the goal accomplishment, but they quickly accommodated their plans to the new situation at the pool until they got interlocked in a conflicting situation solvable only by trading.

As a conclusion, two game variables set the conditions to trigger cooperation: scarcity of blocks, and the imbalance of block distribution among puzzles. It is very likely that both conditions affect turn duration, especially when cooperation is the only alternative of some players to achieve their goals.

5.3 Results of Study 2B. Building puzzle replicas in teams

In order to observe the evolution of coordination between game players without verbal communication, players worked in a similar task as the one assigned to players in Study 2A, but this time the players were distributed in four teams, each one constituted by one pair of players. Study 2B differs from Study 2A in that players worked in teams instead of groups of individuals. Each team was asked to build three puzzles. Two teams were assigned to build their puzzles on top of a smart table and the other two were assigned to a regular table. Each team found at their building tables three puzzle seeds. On separated regular tables, each team had a pool of building blocks. The four collected datasets correspond to each team.

The results showed that the most common strategy adopted by players to achieve coordination was to sequentially build one puzzle after the other. Six out of eight participants exhibited this coordination strategy, and their team performance was very similar. The average time spent by players was 5:48 min. The longest turn duration, and highest average duration of turn were exhibited by the team Smart table 2, whereas the shortest turn duration, and lowest average duration of turn were exhibited by the team Regular table 2 (See Table 5.12).

The round of puzzle completion varied in each team because of the seed size and the coordination strategy. The teams who adopted a sequential strategy completed their first puzzle within the second or third round. The team *Regular table 2* was the only one who did not adopted a sequential strategy. Instead it adopted a parallel strategy and completed its first puzzle at the eighth round. Paradoxically, this team had the fastest completion time, even though it did not have puzzle seeds. It exhibited a brilliant strategy that resulted in the highest performance among all the tested teams. The performance of a team is estimated by its game duration and its consistency of balanced distribution of blocks along the game. The quicker the completion and the higher the consistency the better the team performance

Table 5.12 Statistics of the building block game in Study 2B

Game statistic	Regular table		Smart table	
	1	2	1	2
Game duration	5:29 min	3:18 min	5:43 min	8:44 min
Seed size	2	0	2	1
Completion round 1st puzzle	2	8	3	3
Completion round 2dn puzzle	5	9	6	6
Completion round 3rd puzzle	7	9	10	9
Max turn duration	122 sec	45 sec	59 sec	363 sec
Average turn duration	47 sec	22 sec	34 sec	51.5 sec

The dynamic exhibited by the team Smart table 1 is representative of the sequential strategy cases observed at the game. This team's dynamic is characterized by the status of each puzzle, the turn duration, and the pool status (See Fig. 5.10). The puzzle status presents how the puzzles α, β and γ were built round by round. The players followed a sequential strategy starting with the puzzle α which was completed in round 3.

At that point, puzzle β had two more blocks than the initial seed, and puzzle γ had lost all of them. The imbalance of block distribution at the smart table 1 in turn 3 was calculated as 2.25 (See Fig. 5.11). This means that, even though the team Smart table 1 completed its first puzzle fairly soon, it sacrificed the balanced distribution of resources at the building table. Back to Figure 5.10, it also shows that the turn duration of player B in round 2 was three times the duration of the preceding turn in round 1. It is because player B spent 83 seconds rearranging the pieces available at the building table attempting to complete puzzle α, consuming the blocks of β and γ puzzle's seeds. Between turns 4 and 6, puzzle β grew steadily until it was completed. At that point the imbalance was worse than three turns before: 2.59 averaged standard deviations. Four turns later the third puzzle γ was completed and the building block balance was restituted.

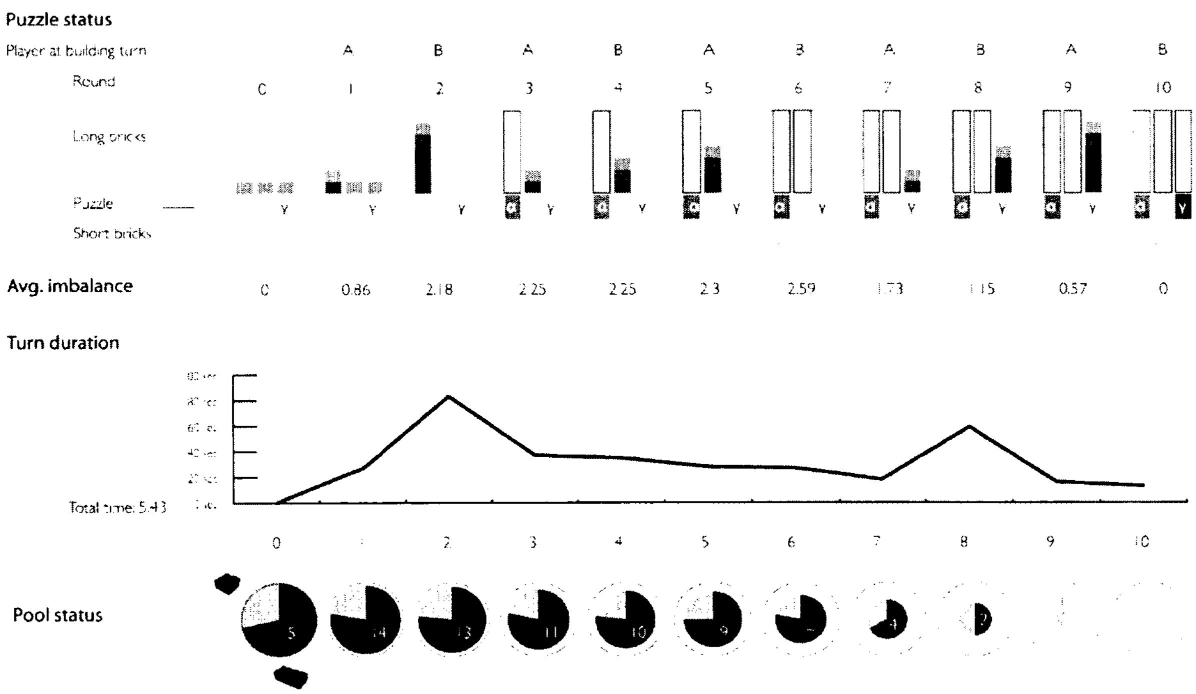


Figure 5.10 Game evolution of Smart table 1 over rounds. α, β and γ represent the puzzles on the smart table. A puzzle letter with solid background means that the team completed that puzzle

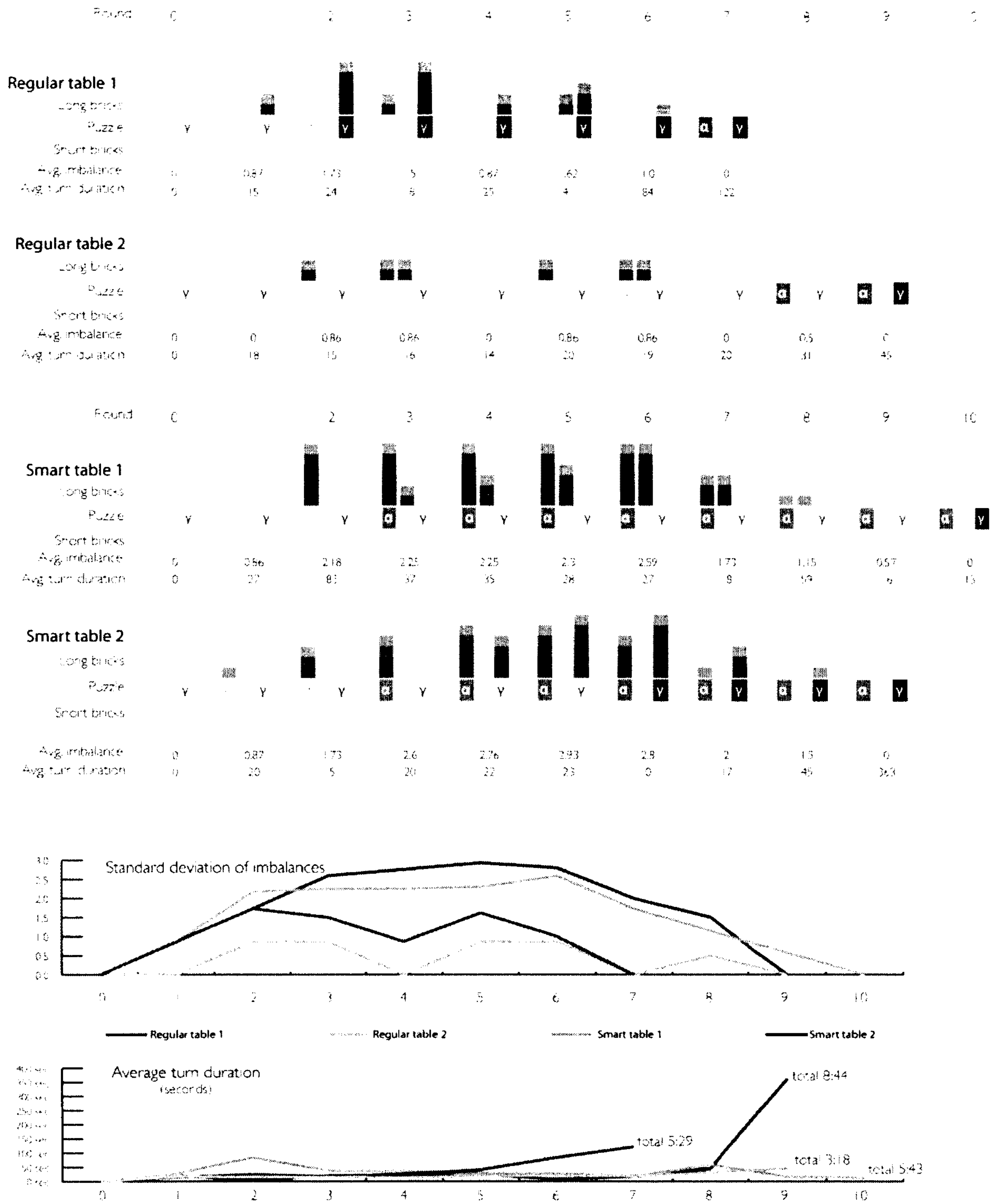


Figure 5.11 Evolution of imbalances of building blocks and turn duration at smart tables

Figure 5.11 describes the evolution of the imbalanced distribution of blocks and turn duration. Whereas the distribution of building blocks in puzzles built on regular tables describes a *bouncing* shape (Regular table1 and Regular table 2), the distribution of blocks in puzzles built on smart tables describes a *bow* shape (Smart table 1 and Smart table 2). It means that a bounce-shaped block imbalance distribution is contained within a threshold of 1.5 averaged standard deviations. In the case of bow-shaped distributions, a peak imbalance close to 3.0 is achieved halfway through the game and then decreases steadily until it reaches a perfect balance at the last round, when all the puzzles were completed.

The average turn duration had a tendency to last slightly longer as the game evolved. Only one of the teams exhibited a dramatic increase at the last round due to block rearranging.

It appears that the smart tables instead of being beneficial for the efficient achievement of the goal, provoke players to push the imbalance far from a moderated equilibrium. However, it is likely that these results are due to sampling error because of the small sample size. The analysis of a dataset from a larger sample is necessary to derive conclusive results. Therefore the researcher refrains to assert that the impact of the smart artifact either benefits or impairs players performance.

As a conclusion, players with no verbal communication achieved coordination by adopting a sequential strategy. This strategy proved to be effective but it sacrificed the balanced distribution of building blocks among puzzles. It seems that players have a high tendency to achieve accountable partial results, regardless of the limitations that such partial achievement entails for the future fulfillment of their larger goal.

CHAPTER 6

FINDINGS AND INTERPRETATION

An early analysis of pedestrians' trajectories in the wild made with Path Analytics, revealed that it is possible to determine the subscription of actors to an artifact's program-of-action by determining the spatial alignment of their executed-programs-of-action. The analysis showed that there is evidence of a pedestrian's subscription to a sidewalk when his/her executed trajectory is aligned to the intended direction of travel defined by the sidewalk's design. In contrast, pedestrians are not subscribed when they exhibit trajectories other than the ones outlined by the sidewalk. For example, a walker wandering erratically on the sidewalk while he/she smokes a cigarette or talks over his/her mobile phone is not subscribed to the sidewalk's program-of-action. Subscribed and unsubscribed trajectories are both socially valid, but the former is prone to elicit cooperation or collaboration among walkers within the same social domain, i.e., walkers present on the sidewalk at the same time, whereas the latter can drive to conflicting interactions.

Once actors' subscription is confirmed, it is possible to count the members of the actor-network and interpret their social interactions. Based on the triadic unit of analysis, several hypergraphs (Kaufmann, van Kreveld, & Speckmann, 2009) of a selection of actor-networks were drawn. Each one exemplifies the general results and findings of the studies. The nodes in the hypergraphs are either human or nonhuman actors involved in the activity. The edges linking actors represent the *within interactions* of actors in the same collective. The shapes grouping sets of nodes and edges are sub-graphs that represent collectives, and the areas of intersection between these shapes represent the *between interactions* of collectives (See Fig. 6.1). The *network size* comprises the total number of networked actors participating in the activity. The *network density* comprises the number of links between actors in the network.

6.1 Actor-networks of pedestrians

The 1 vs. 2 configuration of pedestrians is used as a representative example of the actor-network that emerged in the smart crosswalk studies because it is simple enough to illustrate the complexity of the actor-network, and rich enough to depict the human and nonhuman interactions of both lab studies and street observations. The results of several statistical tests conducted to analyze the *between interaction* of this configuration were statistically significant across all the study conditions. Moreover, this was the configuration picked as the control for the data collection in the lab. Therefore the discussion offered in this chapter is based in this representative configuration and can be extended to other configurations observed in Study 1.

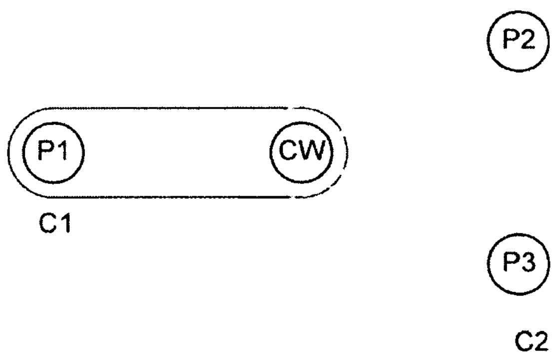


Figure 6.1 Simplified actor-network in the crosswalk study. Configuration of pedestrians 1 vs. 2. P1, P2 and P3 represent one pedestrian each and CW stands for smart crosswalk

The interactions between three pedestrians (P1, P2, P3) and the smart crosswalk (CW) define the three elementary collectives of the actor-network (See Fig. 6.1. Due to the fact that pedestrians P2 and P3 walked as a clique[10] in the same direction, their collectives are merged in a single sub-graph which defines a larger collective named as C2. The collective P1-CW, named as C1, only has two actors (P1 and CW) and it is a general representation of the smallest collective of Study 1's actor-networks, whereas C2 has more than two actors (P2, P3 and CW) and represents the largest collective of Study 1'a actor-networks. C1 and C2 are representative instances of all the collectives formed the actor-networks observed in Study 1. The configurations of pedestrians with an even number of actors in each collective, i.e. 1 vs. 1 or 2 vs.2, can be represented by instances of either C1 or C2 according to their number of actors.

An analysis of their *within interaction* shows that the mediating meaning of C1 and C2 collectives is a hermeneutic *composition* because the smart crosswalk mediates each pedestrian's intentionality by interpreting the ongoing social situation on the crosswalk and then signaling the best Communal sharing-based distribution of space to all the actors in the actor-network (See Table 6.1).

Table 6.1 Analysis of mediation within collectives of pedestrians and the smart crosswalk

Assembly of meaning	Mediation of intentionality			
	Background	Embodiment	Hermeneutic	Alterity
Composition	-	-	C1, C2	-

[10] Clique is defined as a small group of people with shared attributes, in this case acquaintances walking together.

Results of lab studies clearly demonstrated that the smart crosswalk intervention – characterized as the composition of programs-of-action of pedestrians and smart crosswalk – in conjunction with the hermeneutical mediation of pedestrians' intentionality, affected walkers' speed, target and trajectory. Let us interpret the smart crosswalk effects in **full perception** condition in reference to the control run. For the most part, it is possible to assert that the smart crosswalk signals negatively impacted the walking flow because pedestrians took longer to cross the smart crosswalk and their destinations changed. Nevertheless, not all the aspects of their walking flow worsened. The pedestrians' trajectory disturbances were considerably lessened. This constitutes evidence of improvement in coordination. But, in spite of better coordination, the collective's walking flow was slower than in less-coordinated observations. A possible explanation is that pedestrians do not care about how much they need to deviate their course as long as their walking speed maintains its pace. Based on this insight, it is possible to deduce that a walker's priority is to achieve his/her intended target at a constant velocity, regardless of the stability of his/her course.

The analysis of **limited perception** datasets in reference to their control run showed that pedestrians' speed did not change significantly when they walked on the smart crosswalk while it signaled trajectory conflicts or suggested paths. But their target deviation lessened dramatically in that smart crosswalk signals accurately directed pedestrians to their intended targets. Their trajectory disturbance considerably decreased, especially when the smart crosswalk suggested trajectories. An interpretation of these results is that smart crosswalk signals had a positive impact on pedestrians' walking flow even when they had limited access to information of the ongoing social situation.

Pedestrians' immediate priority was not the achievement of the target destination but sorting out a safe path in the short run. While they relied on the smart crosswalk signs, their flow rate slightly decreased. Nevertheless, it is possible to assert that they performed much better compared with the limited perception control run.

Although the difference between pedestrians' behaviors with highlighting and suggesting smart crosswalk modes are not statistically significant, the study results show evidence that the highlighting mode produced lower target deviations and their walking paths were clearer. An interpretation is that the pedestrians improved the coordination of their actions when their attention converges on potential conflicts highlighted by smart artifacts. But their efficiency to circumvent those conflicts diminishes when solutions to get around those conflicts are suggested by the same smart artifacts.

An analysis of the aspects of the *between interaction* of collectives reveals different forms of interaction in the actor-network. While the interaction between C1 and C2 is cooperative, the interaction between members of C2 is collaborative (See Fig. 6.2). C1 and C2 selfishly seek the achievement of their conflicting goals, and each of their programs-of-action are discordant. Their most convenient social interaction was mutual cooperation. But the nature of the *between interaction* inside C2 is different. The collectives P2-CW and P3-CW have an altruistic consideration for each other's goal because their human actors walk together as a clique, their goals are consequent, and their programs-of-action are congruent. Hence, pedestrians in C2 collaborate with each other.

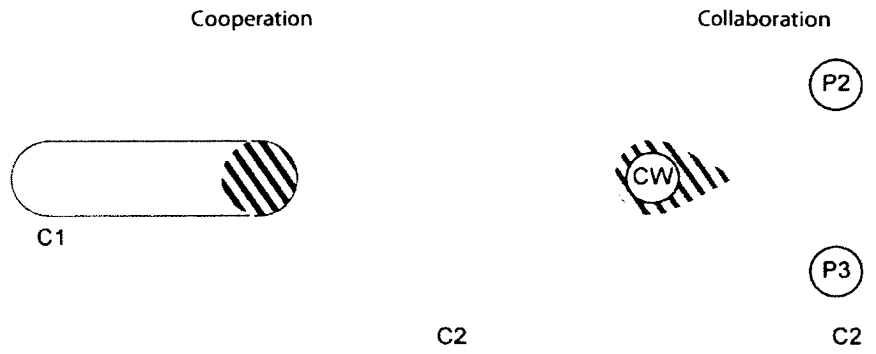


Figure 6.2 *Between interactions* of networked actors in crosswalk study. The hatched area on the left hypergraph illustrates cooperative interaction, whereas the hatched area on the right illustrates collaborative interaction. C1 and C2 represent two collectives. P2 and P3 represent pedestrians and CW stands for a smart crosswalk.

The *between interaction* of collectives is scrutinized when we study their degree of coordination. As discussed in Chapter 4, the degree of coordination of pedestrians is derived from the analysis of their trajectory disturbances. The *between interactions* in **full perception** will be explained first. The general observation is that while the smallest collective C1 has the steadiest action flow with the highlighting mode, it has the jerkiest action flow in suggesting mode. In terms of **cooperation** between C1 and C2 this means that, calling the attention of pedestrians to their potential conflicts (highlighting mode) results in improvements of the walking flow of the collective C1. Consequently, the largest party C2 needs to make a harder effort to maintain its course. In terms of **collaboration** between C2's actors, their effort of keeping a consistent course seems to be balanced between them. The inverted situation is observed when suggestions to circumvent potential conflicts are made to pedestrians. The larger collectives benefit the most from the smart crosswalk suggestions, shifting the burden of adapting trajectory to the smaller collectives.

In **limited perception**, it is not possible to discern which collective exhibits a better degree of coordination. The only evident pattern is the increase of statistically significant differences between the trajectory disturbances of the cooperative collective (C1) as the crosswalk gets crowded. This reinforces the idea that one of the interactive parties makes a greater effort to cooperate than the other.

An overall observation of pedestrians' speed indicates that the more crowded the crosswalk, the slower the walking flow, regardless of the study conditions. The smallest collective was the swiftest, and actors collaborating inside a large collective such as C2 manifested a highly imbalanced trajectory disturbance.

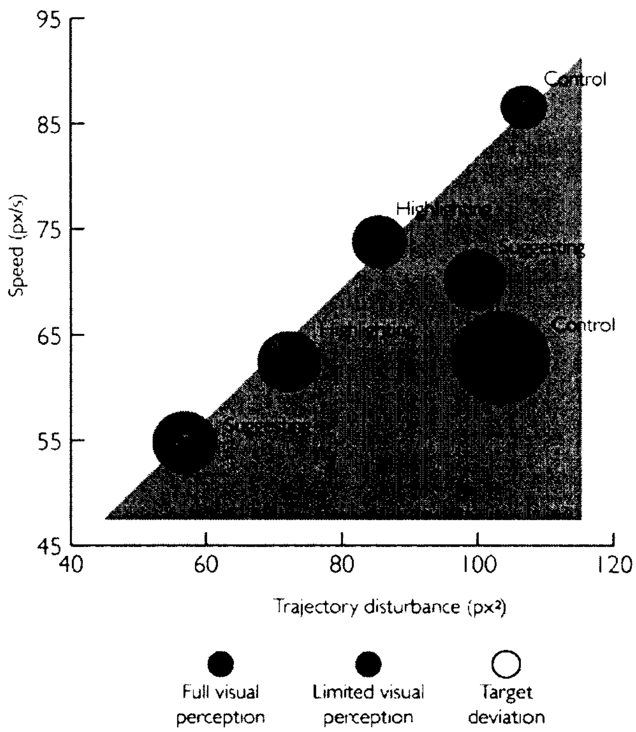


Figure 6.3 Area of correlation between pedestrians' speed and trajectory disturbances

Figure 6.3 illustrates an important aspect of the social interaction of pedestrians. All of the plotted observations are located at the right side of the chart's diagonal, leaving the left side empty. This means that pedestrians with low trajectory disturbances do not walk fast. In other words, in order to walk fast pedestrians need to sort out disturbances. It appears that actor-networks of human and nonhumans have a sort of *social viscosity* that affects the flow of independent action unevenly. While smaller collectives coordinate easily, larger ones struggle to maintain coordination. The observed trajectory disturbance reveals the internal friction of actors, as a result of their attempt to enact their programs-of-action. Such friction, which ultimately renders the actor-network viscous, seems to thicken when people act under limited access to environmental information. It is under those limited conditions when smart artifacts have a higher impact in the actor-network's viscosity and benefit communal action flow across the actors in the network.

6.2 Actor-networks of table game players

In order to present a simplified analysis of the actor-network in Study 2A and 2B the following discussion, supported by some hypergraphs, analyses a subset of the actor-network of each study. In the case of Study 2A, the hypergraphs depict two players out of a group of four, their corresponding puzzles and one smart table. In the case of Study 2B, the hypergraphs depict the two players of one of the teams, their three puzzles and one smart table. The inferences and discussions regarding these simplified actor-networks can be extended to the actor-networks of groups – in the case of Study 2A– or teams – in the case of study 2B – that played at smart tables. The findings of Study 2A and Study 2B are interpreted separately.

6.2.1 Game players in Study 2A. The smart table intervention of Study 2A was designed with a preconceived actor-network which turned out not to be representative of the actual dynamics observed during the study at the lab. The initial assumption was that collectives composed of players together with their puzzles would emerge once the game began, and that the smart table would constitute a black-boxed collective together with the pool of blocks.

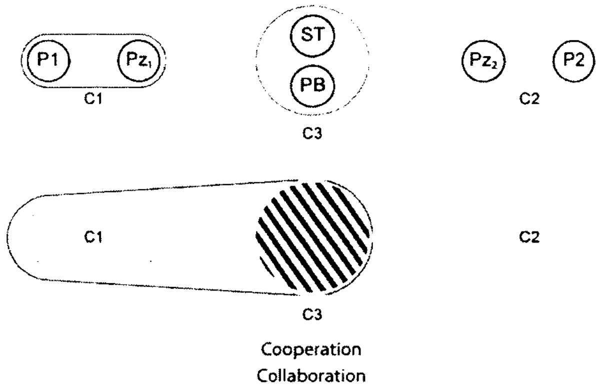


Figure 6.4 Preconceived actor-network in Study 2A. The top hypergraph presents a detailed view of the collectives. The bottom one highlights the expected focus of activity. P1 and P2 represent one player each; Pz_1 and Pz_2 represent P1's and P2's puzzles respectively; ST stands for smart table, PB stands for pool of bricks; C1,C2 and C3 are collectives of actors

Figure 6.4 depicts this assumption, where P1-Pz_1 and P2-Pz_2 are the players–puzzles collectives, and ST-PB is the smart table-pool of blocks collective. The sub-graphs C1, C2 and C3 present a straightforward illustration of the actor-network. It was expected that C3 would be the focus of game activity, where it was intended to observe the *between interactions* of collectives.

Study results and subjects' post-session feedback reflected a different structure of the actor-network. Although it was made clear in the protocol and introduction that the game was not a contest, the actor-network exhibited a structure for competition because players selfishly regarded each other as contenders. It was only in the last rounds of the game, when the scarcity of resources made players realize that each other's goals could be complementary, that the actor-network exhibited a structure for cooperative behavior.

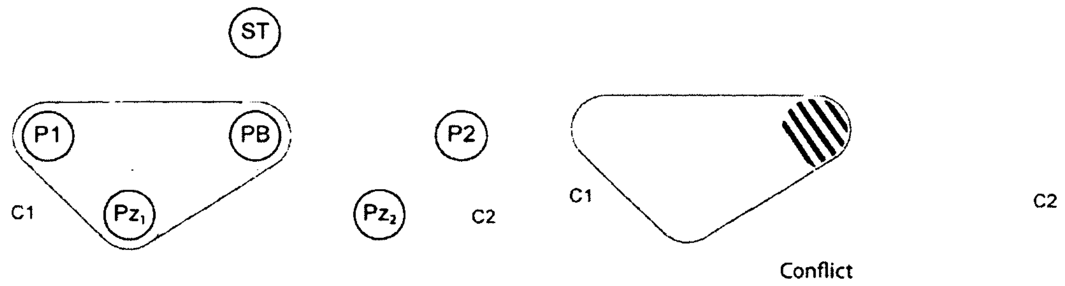


Figure 6.5 Actual actor-network observed in the first rounds in Study 2A. P1 and P2 represent one player each; Pz_1 and Pz_2 represent P1's and P2's puzzles respectively; ST stands for smart table, PB stands for pool of bricks; C1 and C2 are collectives of actors

Figure 6.5 presents an illustration of the actual actor-network during the first six rounds, before players cooperated. The most prominent difference compared to the intended actor-network was that the smart table (ST) and the pool of blocks (PB) did not constitute a black-boxed unit for the players at the table. Instead, the smart table was always acting in background with no major relevance for the players. Although the smart table displayed numerically the pool's status and each puzzle's progress, this information barely came to the players' attention.

Two intersecting collectives constitute the actor-network: C1 and C2. C1 comprises player P1 together with its puzzle Pz_1 and the Pool of blocks PB. Consequently, C2 is composed by P2 together with Pz_2 and PB. The smart table ST is still an actor in the actor-network because its circular design arranged players around itself, but its computational functionality did not mediate the players' understanding of game's activity.

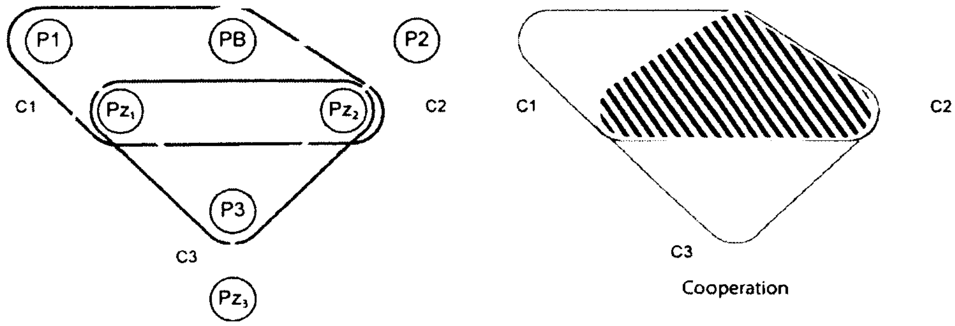


Figure 6.6 Representation of the actor-network cooperation in Study 2A. The left hypergraph presents a detailed view of the collectives. The hatched area on the right highlights the actual focus of activity. P1, P2 and P3 represent one player each; Pz_1, Pz_2 and Pz_3 represent P1's, P2's, P3's puzzles respectively; C1,C2 and C3 are collectives of actors

Close to the round of depletion of blocks in the pool, players loosened their selfish attitudes and embraced their counterparts' puzzles as their own game objectives, as Figure 6.6 illustrates. A player – P3 – who completed his/her puzzle acted as a block mediator between block trading players, opening players' interaction to cooperation. In the actor-network, P3 together with the the incomplete puzzles Pz_1 and Pz_2 comprises the new collective C3. *P3's puzzle* was left out of the collective because the P3 did not offered to trade his/her own blocks.

An analysis of the *within interaction* of collectives in the actor-network shows that the mediating meanings of P1-Pz_1 and P2-Pz_2 are defined as exemplars of *embodied composition* which expresses the players' progress towards the goal completion. The data show that players P1, P2 and P3 read each other's progress through their puzzle's completeness. The mediating meaning of P1-PB and P2-PB is characterized as a *hermeneutical composition* which represents the advent of a conflicting situation in the game. Study results show that players opened up to cooperation right at the moment when the pool of blocks was depleted.

Table 6.2 Analysis of interaction within collectives of players in Study 2A

Assembly of meaning	Mediation of intentionality			
	Background	Embodiment	Hermeneutic	Alterity
Composition	Actual P1–ST and P2–ST	P1–Pz_1, P2–Pz_2	P1–PB, P2–PB	-
Black-boxing	-	-	Preconceived C1–C3 and C2–C3	-

For the main part of the game, the *between interaction* of collectives was characterized by the conflictive directionality of goals and manifested selfish behavior because players anticipated block depletion. The depletion of resources also compelled them to define discordant programs-of-action, and players manifested a selfish behavior. This specific combination of social interaction attributes – conflicting directionality, discordant programs-of-action, and selfishness – have a high potential to result in a clashing interaction unless one of the parties relinquishes his/her selfish attitude. The third-party mediator P3 facilitated the emergence of altruistic behavior between conflicting parties.

While turn duration provides evidence of good coordination for the majority of the players, the distribution of blocks among puzzles shows a contrasting picture. Block distribution increased its imbalance turn after turn, reaching peak values at the penultimate turn. Block distribution went back to balance at the very last turn due to players' cooperation. An important observation in this study is that high levels of block imbalance between puzzles encumbers the achievement of cooperative interaction because, in order to achieve such cooperation, players need to step back to look at all their options, and disassemble their puzzles partially or completely according to their new plans.

Turn-taking affected dramatically the form of sociality of the game because it hindered reciprocity. As a result, players did not feel obligated to each other. The potential to render their programs-of-action congruent appeared only when they conflicted. It is possible to infer that turn-taking delayed the emergence of altruism. As Figure 5.8 shows, players looked after their individual goals, and player B, who completed his/her puzzle first, ended up offering apologies to other players at the last round for overusing long blocks.

In conclusion, the information available to the players, either displayed by the smart table or conveyed by the status of the pool of blocks and puzzles, did not facilitate the realization of imbalances, rendering it difficult for players to keep an egalitarian distribution of resources. In addition, players did not show major consideration for each others' goals and only conflicting interactions made them regard each other as potential cooperative partners. As a result, the group of players as a whole had a hard time achieving a balanced completion of goals. Nonetheless, despite the lack of cooperation, individual players with privileged access to resources had a smoother action flow.

6.2.2 Game players in Study 2B. Study 2B had two sessions. In each session, four players were paired in two teams. One of the teams built its puzzles on a regular table, and the other worked on a smart table. For this study there were no preconceived actor-networks as in Study 2A. Two corresponding hypergraphs illustrate each team's actor-network. In order to simplify their description, team players are named P1 and P2 irrespective of the team (See Fig. 6.7). Each of their players P1 and P2, formed a first collective together with the pool of blocks PB. P1 and P2 also formed a second collective with C3 respectively. C3 is a separate collective constituted exclusively by nonhuman actors: the puzzles Pz_1, Pz_2 and Pz_3. In the case of the team that built their puzzles on a smart table (ST), the actor ST is added to C3. Finally two larger collectives C1 and C2 encompass the actors C3-P1-PB and C3-P2-PB respectively.

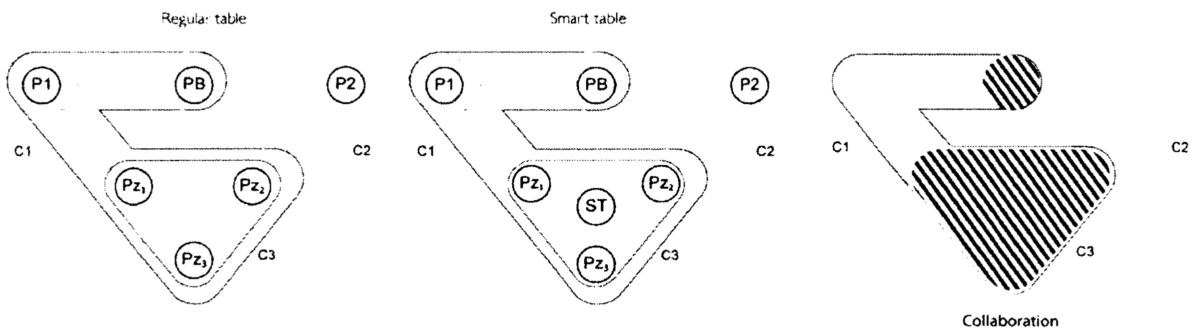


Figure 6.7 Actor-network representation in Study 2B. Left graph presents the actor-network of players playing on a regular table. Middle graph presents the actor-network of players playing on a smart table. Right graph presents the focus of activity of both actor-networks. P1and P2 represent one player each; Pz_1, Pz_2 and Pz_3 represent P1's, P2's, P3's puzzles respectively; C1,C2 and C3 are collectives of actors

The data analysis reveals that none of the teams who built their puzzles on a smart table had a good performance. The sample size of this study is not large enough to confidently assert that the low performance of those teams is due to the effect of the smart table's signals. Hence, instead of interpreting the results of smart table teams in contrast to regular table teams, the results of all the teams are interpreted in reference to the results of the team *Regular table 2*, which had an exceptional performance.

The team Regular table 2 had two *within interactions* among its collectives: the first is represented by the link between any of the two players P1 and P2 and C3. The second is represented by the link between any of the two players P1 and P2 and PB.

Before going further in the analysis of the *within interaction*, it is important to remark that the program-of-action inscribed in the puzzle when the game was designed was intended to challenge cooperation between players by restricting their solution to only one effective way of building the puzzle. The program-of-action inscribed in the pool of blocks was to provide barely enough blocks to complete the puzzles. In regard to the program-of-action of players P1 and P2, the assumption was that each of them would elaborate a plan to build the three puzzles concurrently, but neither of the players would know other's plan because both of them were not allowed to talk.

When P1 and P2 get subscribed to C3's program-of-action, C3 mediated the interaction between the players because it reifies, channels, and conveys each player's secret building plan. According to the framework of human-artifact interaction (discussed in Chapter 3), C3's mediating meaning is characterized as a *hermeneutical translation* (See Table 6.5). On the one hand, it is *hermeneutical* because it conveys two meanings for the incoming player at the building table: i) the distance to the goal completion, and ii) the imbalance of block distribution among puzzles. On the other hand, using ANT terminology, C3's mediating meaning is a *translation* because both the program-of-action of the incoming player at the building table, as well as that of C3, suffer a displacement when they interact. When the current player needs to adapt his/her plan to the puzzles' configuration left by the preceding player, C3's cognitive challenge becomes either easier or harder for the subsequent player.

Table 6.3 Analysis of mediation within collectives of players in Study 2B

Assembly of meaning	Mediation of intentionality			
	Background	Embodiment	Hermeneutic	Alterity
Translation	-	-	P1-C3, P2-C3 P1-PB, P2-PB	-

The evidence supporting this interpretation comes from the observation of a player, represented by P2, who consistently distributed the blocks he brought to the building table in the same fashion as his counterpart, represented by P1. Therefore P2's program-of-action drifted as the result of the last interaction between P1 and C3.

The other *within interaction* of collectives in the actor-network is represented by the links between P1, P2 and the pool of blocks PB. Such interactions are very similar to the interaction of players with C3. PB's mediating meaning is also characterized as a *hermeneutic* mediation of intentionality and assembles its meaning by *translating* its actor's programs-of-action.

An interpretation of the study observations is that the collective C3 is an actor made up of the three in-progress puzzles wherein each one has inscribed a program-of-action aimed to challenge potential cooperation. C3 lacks of a human actor, therefore it lacks of intentionality. Its program-of-action is a composition of the three puzzles' programs-of-action. Consequently, the composed program-of-action of C3 is also to challenge potential cooperation between players, but at a higher degree.

The *between interaction* of collectives for the team Regular table 2, it was characterized by the *consequent* character of C1's and C2's goals because the partial achievements of one of them did not harm the partial achievements of the other. At the end, the achievements of both players fulfilled the team goal. This *between interaction* was also characterized as *congruent* because C1's and C2's programs-of-action exhibited harmonious use of resources. The strategy of building the three puzzles in parallel was consistent and coordinated from the early steps of the process. Finally, both collectives C1 and C2 manifested an *altruistic* consideration for each other. It is possible to infer that this is because the players in either C1 and C2 were explicitly defined as team members at the beginning of the game. Consequent directionality, congruent programs-of-action and altruism characterized their collaborative form of sociality.

In regard to the *within interactions* of the other teams in the study, they exhibited the same actor-network as Regular table 2 did; therefore their *within interactions* were the same. In regard to the *between interactions*, the team Regular table 1 showed a similar *between interaction* to the one of Regular table 2, but their building strategy was not *congruent* during the first rounds of the game. The players at Regular table 1 started with a sequential strategy, but P2 switched to a parallel strategy when she realized the potential conflict of the block imbalance. P2 explained about her change of strategy: "I knew that P1 built a puzzle with long ones, so he was not using short ones [...] At that moment I realized that it would not be possible to complete the puzzles with the long ones, therefore I started to plan how to use the short ones."

As for the *between interaction* of the teams that built their puzzles on smart tables, their building strategies were not consistent. In spite of the players' sequential coordination, the completion of one puzzle partially harmed the completion of the following one. This *between interaction* is also characterized as *discordant* because oftentimes the player at the building table undid what the preceding player had done. The strategy of building the three puzzles sequentially achieved coordination very early in the process, but the imbalance of blocks was disregarded by players in these teams.

As a conclusion, the object of knowledge of the game, to be understood and attained by game players is reified in the actors C3 and PB. These actors act as hermeneutic mediators because they represent the thinking of P1 for P2 and vice versa, resulting in a cooperative interaction in the actor-network. In order to effectively achieve collective goals, keeping a balanced distribution of resources is as important as coordinating activity participants' actions.

6.3 Thresholds of imbalanced distribution of resources

The imbalance of blocks between teams' puzzles in the Study 2B, plotted in the time series chart in Figure 5.10, reveals two distribution patterns along the game. On the one hand, teams with sequential building strategies showed a bow-shaped distribution of used blocks and a longer completion time. On the other hand, teams with parallel building strategies showed a bouncing-shape distribution and a quicker completion time. While parallel strategies prevented the imbalance of used block distribution from going above a threshold of 1.5 averaged standard deviations (*SD*), sequential strategies reached imbalances close to 3.0 averaged *SD.* An analysis of the degree of coordination of players suggests that players in teams whose distribution of used resources describes a bow shape had less compatible programs-of-action than those in teams with bouncing distributions.

Table 6.4 Degree of coordination of team players in Study 2B

Player 2	Player 1	
	Parallel	Sequential
Parallel	High coordination, congruent program-of-action, lowest imbalance	Low coordination, discordant program-of-action, high imbalance
Sequential	Low coordination, discordant program-of-action, high imbalance	Conditional coordination and program-of-action (see Table 6.5), highest imbalance

Table 6.5 Conditional coordination of players adopting a sequential strategy

Player 2	Player 1	
	8 longs	7 longs and + shorts
8 longs	Low coordination, congruent program-of-action, high imbalance	Low coordination, discordant program-of-action, high imbalance
7 longs + two shorts	Low coordination, discordant program-of-action, high imbalance	High coordination Congruent program-of-action, high imbalance

Lets us analyze the implications of two team players, P1 and P2, trying to coordinate on the same building strategy. The players can adopt two possible strategies: build their puzzles sequentially or build their puzzles in parallel. The Table 6.4 shows the degree of coordination of P1 and P2 in round three, just before players coordinated on one of the two strategies. If both players adopt a parallel strategy (shown in the upper-left quadrant), they will be highly coordinated and their program-of-action will be *congruent*. As the data show, it is likely that the level of block imbalance of their puzzles will be below 1.5 averaged *SD* for the rest of the game. If P1 and P2 adopt different strategies (shown in the upper-right or lower-left quadrants), their degree of coordination will be low and their program-of-action will be *discordant*. It is likely that the level of block imbalance of their puzzles will be higher than 1.5 averaged *SD* because one of the players will try to accommodate in one puzzle all the blocks available at the building table (the ones from the puzzle seeds in addition to the ones he/she brings to the table). Finally, if P1 and P2 coordinate in a sequential strategy (shown in the lower-right quadrant), their degree of coordination and compatibility of program-of-action will be conditioned by their strategy to build the first puzzle: using either 8 long, or 7 long + 2 short blocks. Table 6.5 presents this subsequent combination of strategies, that is named *conditional coordination* because it may only happen if players first coordinate on a sequential building strategy. Among the four possible conditionally coordinated strategies all but one yields a low degree of coordination. If both players coordinate on building their puzzles with 7 long + 2 short blocks (shown in the lower-right quadrant), they will achieve a high degree of coordination, their program-of-action will be *congruent*, and the imbalance of their puzzles will be above 1.5 averaged SD. Despite of its high imbalance, this would be a very effective strategy. If both players coordinate on building their puzzles with 8 long blocks (shown in the upper-left quadrant), they will have *congruent* programs-of-action but the sudden depletion of resources would make them quickly realize that their strategy is not viable.

As a conclusion, players P1 and P2 would exhibit a higher degree of coordination and a better chance to articulate compatible programs-of-action if both choose the strategy [Parallel, Parallel] or the conditional strategy [Sequential 7+2 ,Sequential 7+2].

This aspect of coordination in social interaction is extendable to the pedestrians because their decisions about their walking trajectories yield a distribution of the crosswalk's width among the coming and going pedestrians that we can say mirrors the distribution of blocks in the table games.

6.4 Multilayered complexity of actor-networks

The empirical studies described above are synthetic instances of actual situations of interpersonal interaction in the wild. In order to ease the data collection and analysis, the studies were designed to reduce the multiplicity of variables found in real-world situations into a few controllable variables purposely selected to analyze the effects of smart artifacts in people's cooperation and collaboration.

All of the subjects were equally exposed to the same study conditions and interactions with smart artifacts in a laboratory setting without distinction of sex, age or any psychological attribute. The size of the actor-networks was controlled by pre-defining the configurations of the collectives to be studied, and the social norms governing the interactions were synthesized into simple experiment rules. However, social interactions in the wild are characterized by a higher complexity that affects the size and density of the actor-network. Such complexity can be defined as *multilayered* because social, cultural, psychological and design aspects impact the valence of the variables that affect interpersonal interaction in the wild. The specific order in which these layers are presented here does not intend to suggest any ranking among them. The first layer is defined by the *social domain* (Steiner & Stewart, 2009) in which the interactions unfold, i.e., the social and institutional norms derived from the models of sociality. The second layer is defined by the *cultural behavior* of human actors (Maturana

& Varela, 1992), i.e., behavioral patterns which have been acquired in the communicative dynamics of a social domain. The third layer is defined by the *psychological attributes* of human actors (e.g., aggressive, passive, selfish or altruistic). The last layer is defined by the *material and environmental conditions* of the artifacts involved and the place where the interactions unfold, i.e., artifacts, buildings, weather, lighting or other contextual conditions.

Such multilayered complexity can be observed in a crowd of train riders at a railroad station. First, the *social domain* layer: commuters exhibit a more determined walking style than riders at leisure because in weekdays commuters usually walk urged by institutional norms (e.g., the train schedule) or social norms (e.g., not being late for an appointment). Second, the *cultural behavior* layer: the commuters' walking style also vary according to their familiarity to the building's gates and platforms. While commuters recursively use the same platform and gate develop strong behavioral patterns, riders at leisure exhibit erratic trajectories. Third, the *psychological attributes* of train riders: while the social domain of commuters in weekdays determines a selfish consideration for other's, the social domain of train rider families in weekends determines an altruistic consideration within cliques of riders. And last, the *material and environmental conditions* layer: narrow platforms and small lobbies encumber the commuting flow of all the actors in the network.

This research can be extended to the investigation of social interaction mediated by smart artifacts in more detailed representations of social activities by designing empirical studies that take into consideration many more dependent variables from the multilayered complexity of social practices: the social domain, the cultural behavior and psychological attributes of the participants of the practice, and the material and environmental conditions in which the practice is enacted. As a result, the complexity of the independent variables observed would scale up, producing more accurate results about the impact of smart artifacts in the mediation of interpersonal interaction. The core methodology of any future research will be the study of the actor-network structure and the analysis of the *within* and *between interactions* of human participants. It is possible to design studies that investigate each one of the layers of complexity defined above separately or that investigate different combinations of them by using an agent base modeling platform like *Netlogo* (Wilensky, 1999) or *Repast Simphony* (M.J. North, Howe, Collier, & Vos, 2007).

CHAPTER 7

DISCUSSION

The core question of *how smart artifacts can facilitate social interaction* was sharpened by the formulation of the theoretical-conceptual framework and methodology (see Chapter 3). The theoretical-conceptual framework proposes how smart artifacts can partake in social interaction and characterizes smart artifacts as instances of objects of knowledge of a social practice. As such, artifacts' participation in a practice is twofold: first by mediating the activities of other networked human and nonhuman participants and, second, by reifying the epistemic matter of the practice. These two aspects of artifacts as social actors indicate that the core research question explores *smart artifacts signifying the status of an ongoing social activity to its participants,* and also *smart artifacts promoting social interaction between interrelated actors.*

The further definition of the research methodology recasts these two aspects into specific questions. Since this research is exclusively interested in socialities that are based on balanced distributions of resources and obligations, the first aspect of the core research question was reformulated as: *How can smart artifacts effectively signify the underlying moral principle of the relational model for the actor-network of an activity?* The second aspect was honed by choosing social interactions corresponding to the two balance-based relational models: Communal sharing and Equality matching. Consequently, cooperation and collaboration were defined as the forms of social interaction of interest in this research. Both share a key common denominator: the coordination between parties. As a result, the core concern of the research for artifacts promoting social interaction was reformulated in the question: *How can the degree of coordination of participants in an activity be affected by the actions of smart artifacts?* In order to investigate answers to these questions, two studies were outlined in which an instance of a smart artifact, designed to dynamically convey the imbalance of an activity to its participants, was evaluated. The smart artifact's mechanisms to convey such imbalance were: highlighting the potential activity's conflicts, and suggesting alternatives to circumvent those conflicts.

7.1 Propositions for the design of smart artifacts as mediators of social viscosity

This section offers a series of propositions that aim to progressively aanswer to the research questions enunciated in Chapter 1. The propositions are elaborated upon the analysis of the triadic structure of collectives (See Chapter 3), and grounded on the key findings derived from the observations of the empirical studies (See Chapters 5 and 6). The implications of the propositions are then discussed in relation to the domain of interaction design.

Proposition 1. If a smart artifact belongs to a human-nonhuman collective in an actor-network, the design attributes that signify the smart artifact's function characterize the intention of the collective's hybrid program-of-action.

When a human actor subscribes his/her program-of-action to that of an artifact, other actors in the actor-network expect that the resultant collective will execute a hybrid program-of-action. The perceived meaning of such a hybrid program-of-action is strongly shaped by the artifact's design, because the artifact's set of purposes and functions *inscribed* by the artifact's designer are objectively put forward by its subscriber for other actors in the actor-network. As a result, the scope of potential meanings of what the collective will do is narrowed down to what the artifact enables the collective to perform.

Proposition 2. An artifact in the actor-network is a relevant social mediator when it constitutes the focus of activity of human actors' interaction.

Following the definition of *mediator* in Actor-Network Theory, the *relevant social mediator* is an actor that channels and transforms social interaction. In contrast to an *intermediary*, a mediator cannot be defined by its inputs and its outputs. The focus of an activity[11] is defined as the point where actors' action and attention converge. Social interaction is distributed among all of the actors in the network but the epicenter of action does not always coincide at the same focus. The empirical research studies show that the focus of activity jumps from actor to actor – or from collective to collective, enabling their potential for mediation. Among nonhuman actors, only those that are recurrent foci of activity, have the potential to be effective social mediators. If smart artifacts are intended to mediate social interaction, they must constitute the focus of activity for the interacting parties.

Information related to mediation must be displayed at the foci of activity. From the studies reported here, additional information placed somewhere else appears not to be useful in mediating people's programs-of-action. In the case of the table game studies, although the smart table was an actor in the activity, it was not at the epicenter of action. Instead, the focus of activity was located at the blocks, the puzzles and the pool of blocks.

[11] Even though the meaning of *focus of activity* is close to the one of *object of activity*, I refrain from using the latter to avoid overlapping concepts and theoretical positions of my research with Activity Theory. Kaptelinin elaborated extensively on the definition of *object of activity* in: Kaptelinin, V. (2005). The Object of Activity: Making sense of the Sense-maker. *Mind, Culture and Activity, 12*(1), 4-18.

The smart crosswalk study offers a different scenario in which, pedestrians' actions and attention often converged on the patterns signaled by the smart artifact, affecting the activity of the interactive parties.

When coordination is governed by turn-taking, tracking the focus of activity is relatively easy for a researcher because the activity of the actor in turn is at the epicenter of action. The focus of activity for the network is what the actor does and toward whom he/she is acting.

Proposition 3. A mediating smart artifact should complement the cognitive landscape of people with information about what is outside of their perception or unforeseen by them, rather than overwriting their unmediated understanding of the world.

People enrolled in social interaction avoid mediation when information from the world is clear enough to fulfill their goals. However, actors attempting to circumvent potential friction by themselves – unmediated by access beyond their everyday perception – pay a higher cost in coordinating their programs-of-action compared to those who can get around conflicting situations with the help of smart mediators that extend their perception and cognitive landscape[12]. This was observed in the smart crosswalk study when pedestrians' trajectory deviation was higher when they walked on a regular crosswalk compared to when they walked on the smart crosswalk.

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[12] The concept of cognitive landscape refers to what an organism understands about what it perceives from the landscape. Farina, A., Bogaert, J., & Schipani, I. (2005). Cognitive landscape and information: new perspectives to investigate the ecological complexity. *BioSystems, 79*(1-3), 5.

The actual value of mediators of social interaction is revealed when they complete the information people need about facts or trends, thus helping them to make decisions or foresee the consequences of their actions within the actor-network. Networked actors have more complete information of other actors when they act in the same space at the same time. Conversely, networked actors acting in different space or time have limited information of each other. Johansen (1988) provides a two by two matrix that relates space and time in relation to collaboration that further explains further this aspect.

This was partially observed when pedestrians with limited perception walked faster, more accurately and exhibited better coordination thanks to the mediation of the smart crosswalk.

Proposition 4. The networked actions of human and nonhuman actors exhibit social viscosity that hinders the action flow in the actor-network.

Social interaction has a double-edged effect in the actor-network. While interactions pull actors together, they also offer resistance to the execution of the actors' programs-of-action. Such double-edged effects of social interaction represent the *social viscosity* of the actor-network. Social viscosity is defined as the natural resistance of an actor-network to the fluidity of its actors' actions caused by the mutual disturbances elicited while they enact their programs-of-action. Social viscosity has a direct correlation to the size and density of the network. While smaller collectives coordinated easily in the studies, larger collectives struggled to maintain coordinated and balanced interactions. Such viscosity is manifested in the *within* and *between interaction* of collectives.

Evidence of the effects of social viscosity were observed when actors deviated from their trajectories, failing to achieve their goal or change the pace of action.

Social viscosity accounts for some observations of people's behavior that appear unstructured to a rational observer. Such observations are deviations caused by emotional or moral bonds between human actors such as altruism, kinship or hierarchical distances between actors. In the field of behavioral economics, such unstructured behaviors are named as *emotional* or *irrational* (Ariely, 2008). Prospect Theory (Kahneman, 2003) offers a new theoretical perspective for future analysis of the concept of social viscosity of an actor-network in that it models real-life decisions rather than optimal human decisions that are often called rational decisions by game theorists.

Proposition 5. In order to sort out the social viscosity of the actor-network, human actors rely on the information integrity of the actor-network.

The *information integrity* of the actor-network is the completeness, availability and accuracy of the information about the activity of actors in the actor-network.

Human actors in an actor-network with a fixed size and density have the highest chance to quickly achieve their goals if each actor has complete information about the actions of others. *Integral information* means that all actors have available all the relevant information about what other actors are doing in the actor-network, hence they can adapt their own programs-of-action accordingly. Conversely, they have less chance to quickly reach their goals if they have *partial information* about each others' actions. The fact that actors act faster when they have complete information does not mean that the access to information reduces the viscosity of the network. It means that the actors' effort to sort out the disturbances rapidly is catalyzed by their access to information about the actions of other actors in the actor-network.

The empirical study of pedestrians walking on a smart crosswalk (see Fig. 6.3) showed that while there was not a considerable difference between the trajectory disturbance of human actors acting in complete and incomplete information, there was a dramatic difference between their respective action speed. Limited information reduced their speed by one third and increased their target deviation four-fold. In terms of social viscosity, the actor-network exhibited a very similar viscosity in both conditions, but the fluidity of the actors increased when complete information was present-at-hand.

Proposition 6. The social viscosity of the actor-network thins out when actors act coordinately.

While well-coordinated action reduces actors' mutual disturbances, the process of achieving such coordination hinders the fluidity of actors' actions. The empirical studies show that the mediation of social interaction by means of both human and smart artifact mediators improved actors' degrees of coordination. More specifically, the smart crosswalk study demonstrated that smart artifacts can ameliorate social viscosity more effectively under conditions of limited information than under conditions of complete information.

In Study 2A and Study 2B, even though the smart table was not the focus of activity, the game dynamics observed in the studies confirm the finding that actors' coordination thinned out social viscosity. Moreover, the game dynamics of Study 2B showed that the best coordination strategies maintained a low imbalance of blocks. This suggests that the imbalance of resources is a good indicator of the dominant relational model (balance-based or hierarchical) of the social group.

Proposition 7. Cooperative interactions of human actors benefit from smart artifacts that highlight potential conflicts. Conversely, collaborative interactions of human actors benefit from smart artifacts that suggest solutions to circumvent a forecasted conflict.

For the most part all of the interventions of the smart crosswalk improved the pedestrians' coordination. However, there are important differences in their effects on pedestrians' speed that define their usage in both cooperative and collaborative interaction.

In the case of *cooperative* interaction characterized by a c*onflicting* directionality of participants' goals, a *discordant* programs-of-action and a *selfish* consideration for another's interest, participants in an activity have a better chance to coordinate if smart artifacts located at the foci of activity adaptively highlight potential conflicts.

In the case of *collaborative* interactions characterized by a *consequent* directionality of goals, a *congruent* programs-of-action and an *altruistic* consideration for another's interest, participants in an activity have a better chance to coordinate if smart artifacts located at the foci of activity adaptively suggest trajectories.

Proposition 8. Activity participants achieving accountable goals are more likely to attain coordinated interaction if the number of participants does not match the number of goals.

In balanced relational models of social interaction, activity participants evenly distribute portions of the activity's overall goal among themselves. If the goal can be split into discrete sub-goals, then each participant develops a sense of responsibility for only a set of such sub-goals; this results in preventing participants' coordinated interaction. When one or more sub-goals cannot be allocated among the participants, then they are forced to coordinate in order to complete the overall goal.

Proposition 9. Collective goals that require a balanced distribution of resources can be achieved with low social viscosity if participants not only act coordinately but also maintain a balanced allocation of resources along the process.

Participants in an activity have a higher chance to reduce social viscosity if they allocate the resources to be used so as not to exceed an imbalanced dispersion threshold. In the case of Study 2B the *thinnest* social viscosity was observed when players adopted a parallel strategy that manifested an imbalance dispersion threshold of 1.5 standard deviation. High levels of imbalance among puzzles in Study 2B encumbered the achievement of cooperative interaction. A smart artifact must be aware of the imbalance and signal when the threshold is exceeded.

Smart mediators designed to promote coordinated actions between human actors in an actor-network can escalate their mode of signifying imbalances of resources from highlighting potential conflicts to suggesting trajectories once the imbalance exceeds the dispersion threshold. This assumption requires future experimentation in laboratory conditions.

CHAPTER 8

CONCLUSIONS

This research adopted Actor-Network Theory (ANT) as the theoretical basis for the study of artifact-mediated activities within a social practice. ANT argues for human and nonhuman actors as symmetrical social actors who constitute a network of actors that articulate their programs-of-action when they participate in an activity. Such articulation is the origin of transient collectives that emerge and dissolve as the activity unfolds. By using ANT this research proposes a triadic unit of analysis of social interaction mediated by smart artifacts. Such triadic unit of analysis accounts for the interactions *within* and *between* collectives in an actor-network. The *within interactions* are those that hold together humans and smart artifacts inside a collective and put forward the collective's assembled meaning for other actors in the network. The *between interactions* are those that occur among collectives and articulate their goals, programs-of-action and altruistic or selfish considerations for others, producing social interactions such as cooperation or collaboration.

An analysis of interaction in a social activity in which model of sociality is primarily based on Communal sharing and Equality matching, shows that networked actors present mutual resistance when they enact their programs-of-action. Consequently, an actor-network exhibits *social viscosity* that hinders social interaction. Any form of mediation of social interaction affects the social viscosity of an actor-network, but some mediators are better suited for the improvement of coordinated interaction, deriving into cooperative or collaborative interaction depending on the parties' goal-directionality, the compatibility of their programs-of-action and the emotional considerations for each other. In what follows, a response to the over-arching research questions is offered supported in the propositions discussed in Chapter 7.

8.1 Responses to research questions

The central question of this research is : *How smart artifacts can facilitate social interaction?* Responding to the question from the research findings, encompasses several equally important factors, presented below. All of the propositions to which the discussion refers are elaborated in Chapter 7.

- **The dominant form of sociality of the interacting social group.** Four models of sociality are characterized by the Relational Model Theory: Communal sharing, Authority ranking, Equality matching and Market pricing. These models underline the moral principles that guide the social interaction of a human group. This research explored Communal sharing and Equality Matching that account for social groups in which individuals are non-hierarchically organized and have balanced privileges. As a result, the smart artifacts partaking in the actor-network are *enactments* of the dominant moral principles that prompt the preservation of social balance.

- **The information integrity of the actor-network.** The more complete the information of the actor-network the higher the chances of coordinated interactions among people. Smart artifacts should seek to complete the information integrity of the actor-network (See Proposition 5 in Chapter 7).

- **The mechanism of mediation of meaning assembled by humans and smart artifacts.** This mechanism regards the double-edged interaction of human and nonhuman actors *within* a collective. On the one hand, the *assembly of meaning* accounts for the ways in which humans and artifacts articulate their programs-of-action to produce meaning. On the other hand, the *mediation of intentionality* accounts for how a mediating artifact reifies the assembled meaning. A framework of human-artifact mediation is offered in Chapter 3 and examples of how to use it are described in Chapter 6.

- **The kind of social interaction to be facilitated**. This research investigated how smart artifacts facilitate coordination as a contingent condition for the emergence of cooperation or collaboration (See Proposition 6 in Chapter 7). Smart artifacts that put forward forecasted conflicts between networked human actors are prone to facilitate either kind of social interaction: cooperation or collaboration (See proposition 7 in Chapter 7). Cooperation and collaboration are two types of social interaction akin to balanced forms of sociality (extensively discussed in Chapter 3).

These four factors described above characterize the triadic structure of social relationships of collectives that were discussed in Chapter 3 and used as a methodological framework for the analysis of this research's empirical studies. Such triadic structure is an instrument for the analysis and design of networked mediating artifacts.

As for the complementary questions that motivated this research, and other questions that emerged along the path of inquiry, the following responses are offered:

- *How can smart artifacts mediate the mutual understanding of people when they interact?* Schutz' interactionist explanation about subjective and objective meaning of social action partially responds to this question. Two actors achieve a mutual understanding when the objective meaning of their enactments converge with their subjective – intended – meaning. Based on Schutz' explanation, this complementary research question was redefined as: *How can artifacts effectively signify the underlying moral principle of the relational model for the actor-network of an activity?* Smart artifacts' signals effectively mediate social interaction only if the smart artifact is at the *focus of activity* where subjective and objective meaning are more likely to converge (See Proposition 2 in Chapter 7). Other important aspects that impact the effectiveness of smart artifacts are an actor-network's information integrity, its social viscosity, and the design of the smart artifact. The Propositions 1 and 3 argue for the relevance of the artifact's design attributes in the communication of the moral principles and the meaning of its interactive functionalities .

- *How can the design attributes of smart artifacts promote social interaction between interacting actors?* Social interaction – as a subject of inquiry of this research – was narrowed down to two specific forms of interaction: cooperation and collaboration. Both are equality-based forms of social interaction (See discussion in Chapter 3). The analysis of these two forms of social interaction demonstrated that coordination is a contingent condition for their emergence. As a result, this complementary research question was honed to: *How can the degree of coordination of participants in an activity be affected by the actions of smart artifacts?* The research findings indicate that the degree of coordination is positively affected by any mediator, but at the same time every mediation can delay the fluidity of social action. The challenge for smart artifact designers is to design social mediators that do not hinder the fluidity of social action. The research offers two specific propositions to tackle this challenge. Proposition 7 argues that the attention on forecasted conflicts signaled by a smart artifact improves actor's coordination. Proposition 9 offers a principle for the improvement of the degree of coordination of groups with common goals (see Chapter 7).

8.2 Theoretical contributions

While user-centered design denies the ascription of control to artifacts assuming humans as the acting party, the stance of object-centered sociality adopted in this research is open to distributing the system's actions in a network of actors that includes artifacts. Object-centered sociality is defined as the construction of socially accepted and practical truth by a group of people whose activity is materially mediated and centered around incomplete and constantly unfolding objects of knowledge. Object-centered sociality can certainly contribute to design and research in ubiquitous computing and evolution of smart artifacts because humans are dislocated from being the *users of* to being among the *participants in* a distributed system.

Whereas for the user-centered approach the domain of action is constrained to the user's plan of action, the concept of program-of-action in Action-Network Theory broadens the domain of action to multiple forms of participative intervention in a network of actors. The concept of program-of-action is applicable to the design of artifacts' affordances and constraints. To Latour, the program-of-action is inscribed to nonhuman actors and enacted by humans, whereas to Norman, the program-of-action is inscribed in the artifact's affordances and constraints with which the user interacts. This research suggests that the design of smart artifacts can be enriched by rethinking affordances and constraints as mechanisms for distributed human-nonhuman collective action.

Finally, the articulation of an object-centered sociality approach to augment interaction design methods opens up the user-artifact dyad by embracing diverse kinds of participants and practices, thus facilitating design for mediated social interaction.

8.3 Methodological contributions

The third complementary research question defined in Chapter 1 asks: *What are the methodological implications in a design process of ascribing autonomy and adaptability as properties of everyday artifacts?*

The main methodological implication of ascribing autonomy and adaptability to everyday artifacts is that those properties stretch the object of inquiry of interaction design from how to make computational artifacts usable to how to make them socially adept. This entails a conceptual shift in designers' approach to the design of such artifacts. Instead of regarding everyday artifacts as mere tools or equipment, they need to be considered as agents with capacity for action in social contexts.

The research adopted a post-humanist position to tackle this conceptual shift. Based on the notion of *social practice*, smart artifacts are repositioned within social activities as the binding actors that can hold together the actions of human actors subscribed to such activities. Based on Actor-Network Theory, this research recognizes that artifacts and humans share the capacity for influencing society and mesh with each other, constituting hybrid social actors. From this standpoint, this research offers a triadic structure of networked social interaction as a methodological instrument to investigate how smart devices perceive their social setting and adaptively mediate people's interactions within activities. Such a triadic unit of analysis accounts for the interactions *within* and *between* collectives in actor-networks. The *within interactions* are those that hold together humans and smart artifacts inside a collective and put forward the collective's assembled mediating meaning for other actors in the network. The *between interactions* are those that occur among collectives and characterize the dominant model of sociality of the actor-network.

This research envisions that such triadic structure can be used in an interaction design process as an instrument for the analysis of activities and the identification of their *foci of activity* (See Proposition 2 in Chapter 7). Moreover, the proposed triadic structure is an instrument for the evaluation of the social effects of smart artifacts in an actor-network because the study of the *between interactions* reveals the types of social interaction in the triad – cooperation and collaboration in the case of this research – by describing the directionality of actors' goals and the alignment of their programs-of-action.

Researchers who want to design new instances of empirical studies aiming to study cooperation or collaboration following the methodology used in this research need to take into account the following methodological aspects:

1. Define a social practice to be studied and select one of its activities.

2. Identify the dominant relational model of the social practice and understand the set of norms and values that define its social domain, and the cultural behaviors of human participants that engage and affect the practice.

3. Define the size, scope and density of the activity's actor-network by tracing the interactions that conduct action.

4. Map the network of human and nonhuman actors in hypergraphs that describe the collectives of actors. Identify which artifacts have the highest potential to become smart artifacts by determining which nonhuman actors are located at the most relevant foci of activity. (See Proposition 2 for the definition of a focus of activity).

5. Analyze the *within interactions* of collectives to understand the mediation meaning of their hybrid actions.

6. Analyze the *between interactions* to understand the aspects that define the interactions between collectives: directionality of goals, the compatibility of their programs-of-action and consideration for others' interests. Specify if the type of coordinated action is either cooperative or collaborative.

7. Determine the degree of coordination of actors' programs-of-action.

8. Design smart artifacts that signify the mediated meaning identified in aspect (5) and that promote the type of coordination specified in aspect (6). Propositions 3, 5, 6, 7, 8 and 9 provide important guidelines for the design of such smart artifacts.

9. Deploy smart artifacts in the social practice and evaluate their impact in the *social viscosity* of the actor-network (see Proposition 4). Such evaluation can be made by repeating aspects (6), (7) and (8).

Another methodological contribution is the software *Path Analytics*. Its ontological structure is based on Schutz' interactionist study of meaning-context. Path Analytics decomposes activities into actions for which the building blocks are discrete acts. The software proved to facilitate the study of human activities and interactions of each actor in the studies. Path Analytics was designed as a mode of analysis for this research, enabling fine-grained depiction of the enactments made by triadic human-smart artifact-human collectives.

8.4 Constraints and limitations of the research

The empirical studies that were designed to investigate cooperation and collaboration generated valuable initial results as proofs of concept for the elaboration of future research and design. Methodological constraints that set the boundaries of applicability of the results discussed above and the Propositions formulated in the previous chapter include:

- The empirical studies were designed for non-recursive interaction between subjects, i.e., a null shadow of the future.

- The assessment of the degree of coordination is based on Proposition 1, which means that the degree of coordination does not account for the subjective meanings of people's actions, but rather it remained constrained to the objective meaning of the actions people put forward to other actors when they participated in the studies.

- The resources employed in the experiments – the narrow width of the smart crosswalk and the number of building blocks – were purposely very scarce.

- The lab environment partially reflected the kinds of actual interaction of pedestrians on street sidewalks (modeled from observations of pedestrians on city streets). However, along the studies participants developed sympathies for each other that may have biased their behavior in the study in contrast to the *anomie* of interactions on a sidewalk in the wild.

- The results of these studies cannot be directly extended to the design of smart artifacts in which the achievements of people looking for cooperative or collaborative interactions are intended to be assessed or evaluated, for example in the case of an office working environment. This is because the relational model in such competitive situations is not based on Communal sharing or Equality Matching socialities but in either Authority ranking or Market price models. In order to explore other relational models of society it is necessary to conduct studies with smart artifacts which behavior reflects the dominant moral principles of the selected relational model. Important developments in social environments dominated by those forms of socialities have been carried out using different methodologies than the one implemented in this research in the field of Computer Supported Cooperative Work (K. Schmidt & Simone, 1996).

These methodological constraints exclude the applicability of the Propositions formulated in Chapter 7 in instances of design for social interaction in which i) the probability of recursive interaction – the shadow of the future – is higher than zero, ii) there is no intervention by mediating artifacts, or iii) the relational model of the social group to be studied is not based in balanced privileges and obligations.

The empirical research had some limitations of access to participants for the pilot studies and for conducting studies in the lab. The lab space was not a dedicated space for the studies therefore its availability was limited, preventing the repetition and fine-tuning of the studies dynamics and elaboration of the design of the smart artifacts.

8.5 Future research

The results of the study of pedestrians demonstrates that the mediation of the smart artifact consistently improved the degree of coordination in comparison to the controls, but the speed of action was highly compromised. Among the results of pedestrian interaction mediated by a smart crosswalk, the ones that describe faster speeds are those under full visual perception. However, the results never reached the speed of the control group. A diagonal line in Figure 8.1 presents the threshold of speed achieved in the studies, indicating that there is an interesting opportunity to continue this research exploring how smart artifacts can improve the information integrity of the actor-network in such a way that actors achieve a high degree of coordination and maintain highly fluid action.

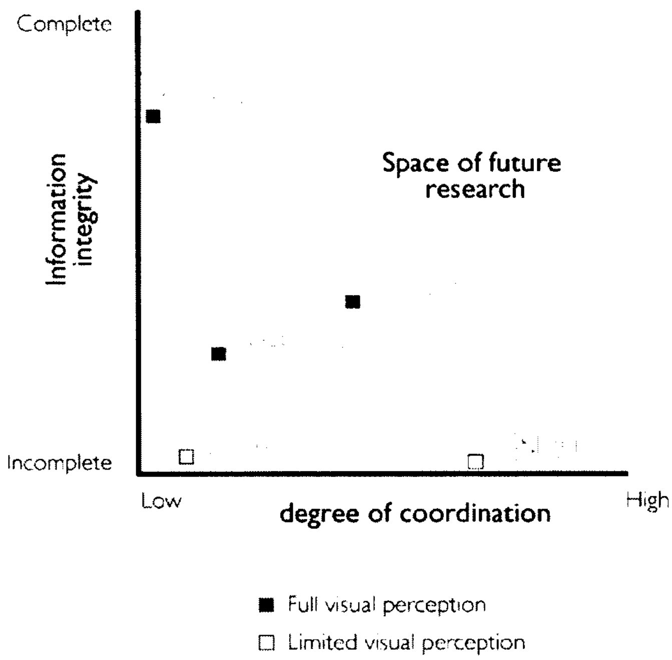

Figure 8.1 Space of future research

A second space for future research is elicited by the observation of an imbalance threshold of the distribution of resources when teams of game players acting with incomplete information about each other's actions achieved high coordination. The question elicited is: *Is an imbalance threshold the cause or the result of coordinated allocation of resources?* If it is the cause, then coordinated forms of social interaction could be achieved by signaling to participants how much of the increment or reduction of the imbalance of resources in an activity is produced by their actions. On the other hand, if such imbalance is the result of participant's coordinated action, then it can be used to assess the degree of coordination of an activity as it unfolds over time.

A complementary aspect relative to the imbalance threshold is the communication of such imbalance to the interacting parties. The observations in the empirical studies show that the information must be placed at the foci of activity, but the visual, haptic or sonic design of such information needs additional exploration. It is possible to foresee that the properties of binary interpersonal relations described in Chapter 2 are a good mathematical principle for the exploration of how to represent the magnitudes of imbalance using symbolic and non-symbolic methods (See Meert, Grégoire, Seron, & Noël, 2012). Further exploration of this aspect of communication design is key for the integrity of information for human participants.

This research can be extended into the investigation of cooperation and collaboration in other social practices with a higher complexity than the ones observed in the design experiments. In order to scale up the complexity of the studies conducted in this research and to design new studies, it is necessary to take into account multilayered dependent and independent variables. "Multilayered" variables are variables that are affected by the social norms of the practice, by the cultural behaviors and psychological attributes of actors, and by smart artifacts deployed in different environmental conditions (See Fig. 8.2). Such extensions of the research could be developed by implementing agent-based modeling and simulation (ABMS) in which attributes of human and nonhuman agents are modeled, instantiated and simulated in an *artificial society* from which the social viscosity of a sample of agents would be observed and analyzed using the same methodological approach as the one used in this research.

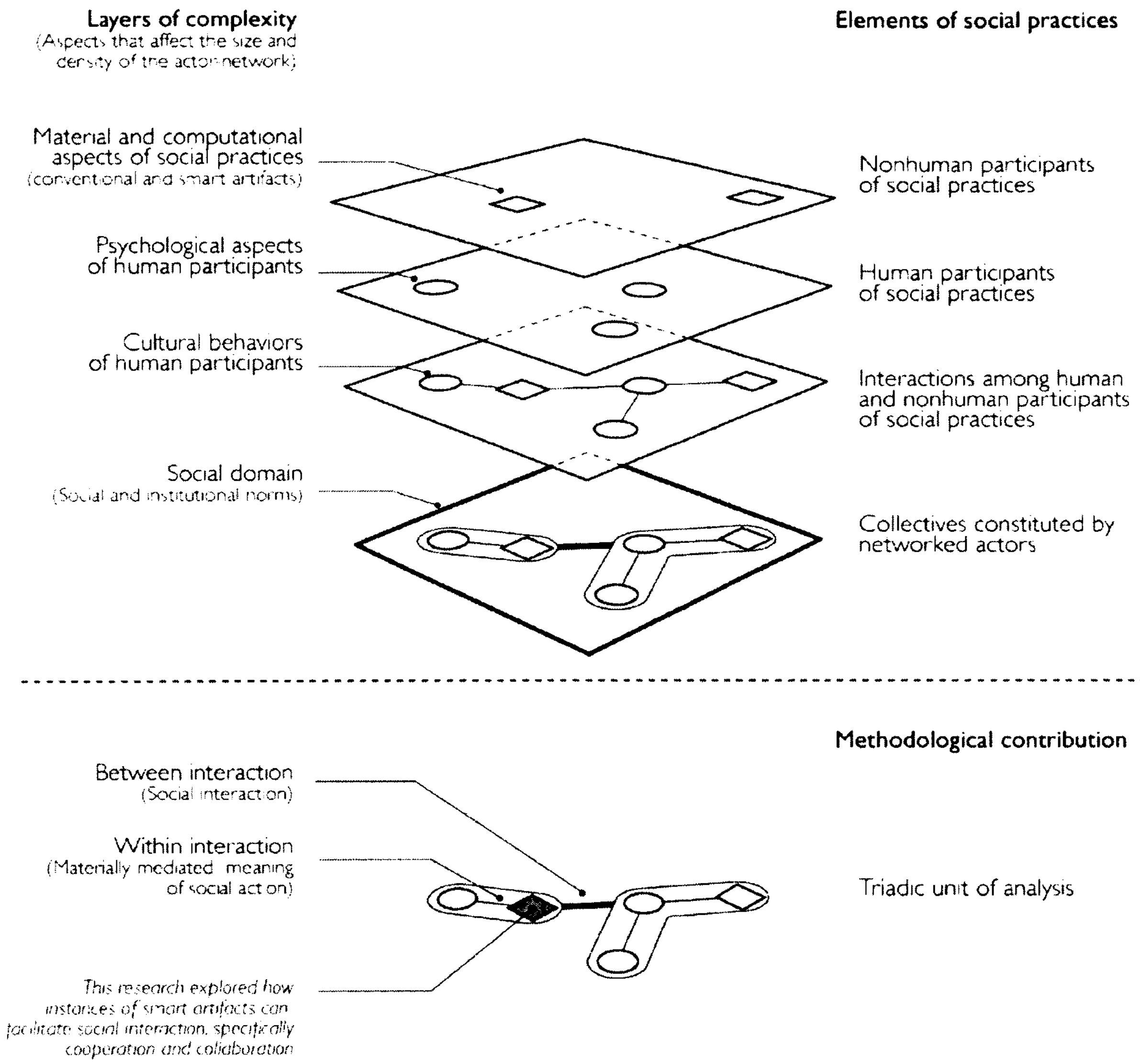

Figure 8.2 Multilayered complexity of social practices and situations of design experiments towards a methodology for smart artifact design

The video analysis software *Path Analytics* was custom made for this project, proved to be a very useful laboratory tool. Although it is a functional prototype that served its purpose accurately and robustly, it has lots of potential to be extended and improved. The following extensions are foreseen: i) the enabling of real time video input,

ii) the implementation of computer vision algorithms that facilitate the process of tracing subjects' trajectories, and iii) the use of algorithms for the correction of the perspective of the footage, and that can present a planar view for analysis.

Another space for future research is the exploration of algorithms for the forecasting of actors' actions used in *Path Analytics*. This research did not intend to deeply explore the techniques developed in computational data mining and artificial intelligence, but it relies on the feasibility that such techniques will be able to accurately estimate the objective meanings of people's actions and render smart artifacts even smarter. It is also important to implement more sophisticated data mining algorithms that can predict with better accuracy potential conflicts in trajectories. There are also important improvements to be made in regard to the usability of the graphical interface.

APPENDIX A.

CONSENT FORM OF SMART CROSSWALK AND SMART TABLE STUDIES

INSTITUTIONAL REVIEW BOARD
ILLINOIS INSTITUTE OF TECHNOLOGY

TO: Judith Gregory/Juan Salamanca

RE: "Agent Based Interaction Design: Sociality with Smart Artifacts"

IRB #: IRB# 2011-121

DATE APPROVED: January 17, 2012

The Institutional Review Board (IRB) has reviewed and approved the above referenced protocol which will involve human subjects. It is the opinion of this IRB that the rights and welfare of the individuals who are to be studied will be completely respected and that informed consent will be obtained in a manner consistent with IIT policy governing the protection of human subjects.

Important: Keep this letter with your records. Your approval number, shown above, should be used in all correspondence with the IRB office so that we can identify your project.

The IRB would like to call your attention to some of your obligations as principal investigator. Any changes in the protocol or in its procedures, a change in the principal investigator or other research personnel, and any significant adverse effects or injury to subjects must be reported to the IRB immediately. IIT policy requires the retention of all records relating to the IRB and to human subjects activities for at least six years after completion of the research. Records, including applications, amendments, signed consent forms, and collected data, must be accessible for inspection at any time and for copying by authorized representatives of IIT, HHS, or the specific agencies sponsoring the research.

Only the informed consent form stamped and dated by the IRB Executive Officer can be reproduced and used in this study. Federal regulations require that an IRB conduct continuing review of research not less than once per year, regardless of whether initial approval was via full board or expedited procedures. Please be aware that your current IRB approval is valid for one year. You must submit a renewal application for IRB review prior to the expiration in order to obtain IRB approval for the next approval period. If the current approval expires and you do not obtain approval for another approval period, research on this study, including subject enrollment, must cease until you regain approval. If you have questions about your obligations as principal investigator, please contact the Office of Research Compliance and Proposal Development at (312) 567-7141.

Sincerely,

Scott Morris /SK

Scott Morris, Ph.D., Chair
Institutional Review Board

CONSENT FORM

Effects of computational interactive objects in social groups

This consent form describes the purpose, procedures, risks, benefits of participation, and measures to protect participants in the research study in which you are being asked to participate. Your participation is voluntary and you may withdraw from the study at any time without penalty.

Purpose of the study

The purpose of this research is to learn how the actions of computational interactive objects may influence people's decisions and actions. Such objects are also known as smart artifacts or smart objects. The information collected will be used to envision future objects that will have small computers embedded in them.

Confidentiality of data

Your voice, face and actions will be recorded during the experiments by using sensors, audio and video recorders, photo cameras and questionnaires. All research data will be kept in the researchers' possession, and will be used for research purposes only. Your data will be encoded to ensure confidentiality of the materials. The original video, audio and photographic documentation in which your voice, face and actions appear will be known to the researchers but will not be revealed publicly. If any visual material is used in a scientific publication, research report or research presentation, your name will not be used and your identify will be concealed by editing of the video footage and/or photographs.

What is involved in the study?

You will take part in three studies that last for 4 hours altogether, including lunch. These are:

Study 1: Building a replica of a Lego model. You will be asked to build two small replicas of a Lego model on a smart table. At the table there will be other people building their own models. This study lasts for 1 hour and 10 minutes.

Study *2: Pedestrians walking on a smart carpet.* You will be asked to walk several times along a corridor with some objects at hand – strollers, umbrellas or roller bags. There will be other people walking on the corridor with you. This study lasts for 1 hour and 30 minutes.

Study *3: Self-serving lunch.* You will be asked to have lunch with other participants. You will be seated at a designated table and you will serve yourself portions of the food brought to the table. This study lasts for 1 hour and 20 minutes.

This activity is not a food tasting study. A catering service will be hired to guarantee the food quality. You must confirm to the researchers that to the best of your knowledge you do not have food allergies. You can withdraw at any time if you believe that the food served can put your health in risk, for example, if you cannot eat certain type of the food.

Immediately after the last of the three studies, you will be asked to fill out a written questionnaire about the choices you made, the actions you did, and the interactions you had during all the studies.

Information to be collected

The researchers will collect your name, telephone number, age and record the date in which you participate in the study procedures. In addition, movement sensors, video and photo cameras, and audio recorders will record your actions during all the activities. The researchers may observe you and take notes of your actions.

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Although your participation involves no future obligation, you may be contacted after this session to discuss your responses to the questionnaire

Risks of the study

The activities have been designed to minimize physical or emotional discomfort to the participants. To ensure confidentiality, all data will be encoded so that your name is not associated with any video and audio recordings, photographs or the questionnaire. The principal researcher Juan Salamanca is available to you to discuss any issues. Juan Salamanca can be contacted at (312) 576 4381.

Any further questions about the research and your rights as a participant will be answered if you contact the project director, Professor Judith Gregory, Institute of Design at (312) 315-3371.

Benefits of taking part in this study

There is no direct benefit to participants.

The expected outcome of this research will benefit ubiquitous computing researchers and practitioners interested in making the interaction between humans and computers smarter, more intuitive and more socially apt. The researchers expect that the conclusions and insights derived from this project will help designers to design socially inspired artifacts that may promote cooperation and coordination among people.

Compensation for your participation

You will receive a modest honorarium of a $25 debit card at a local vendor.

Disclaimer

The Illinois Institute of Technology is not responsible for any injuries or medical conditions you may suffer during the time you are a research subject unless those injuries or medical conditions are due to IIT's negligence. You may address questions and complaints to Glenn Krell MPA, CRA, Executive Officer of IIT Institutional Review Board at (312) 567-7141.

Consent

The research project and procedures associated have been explained to me and I have a satisfactory understanding of them. The questions I have asked have been answered to my satisfaction. I agree to voluntarily participate in this activity, understanding that I may withdraw without penalty at any time.

I have received a copy of this consent form for my records.

Subject   Date

*This consent form is valid only if stamped by Executive Officer of IIT IRB.

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APPENDIX B

TABLES OF TIER 1 AND TIER 2 TEST RESULTS OF TRAJECTORY DISTURBANCES OF PEDESTRIANS WALKING ON SMART CROSSWALKS

Summary of test results of trajectory disturbances of pedestrians walking in opposite direction – **tier 1**, in **full** perception condition, and **highlighting** mode. (FP-H-T1)

Configuration	North collective mean of disturbance	South collective mean of disturbance	SD of means disturbances	Statistically significant	Effect size
1 vs. 1	92.1	88.2	2.8	-	-
1 vs. 2	50.7	120.6	49.4	Yes	d = 0.33
1 vs. 3	47.6	75.5	19.7	-	-
2 vs. 2	122.1	84.3	26.7	-	-

Summary of tests results of trajectory disturbances of pedestrians walking in the same direction – **tier 2**, in **full** perception condition, and **highlighting** mode (FP-H-T2)

Configuration	P1 mean disturb.	P2 mean disturb.	P3 mean disturb.	SD of mean disturb.	Statistically significant	Effect size
1 vs. 2	85.9	66.0	-	14.1	-	-
1 vs. 3	63.8	72.6	88.7	12.6	-	-
2 vs. 2 north	80.4	78.8	-	1.1	-	-
2 vs. 2 south	154.8	71.9	-	58.6	Yes	d=0.73

Summary of test results of trajectory disturbances of pedestrians walking in opposite direction – **tier 1**, **full** perception condition and **suggesting** mode (FP-S-T1)

Configuration	North collective mean of disturbance	South collective mean of disturbance	SD of means disturbances	Statistically significant	Effect size
1 vs. 1	131.6	65.2	47.0	Yes	d = 0.71
1 vs. 2	117.9	56.3	43.5	Yes	d = 0.33
1 vs. 3	121.1	92.0	20.5	-	-
2 vs. 2	115.8	78.2	26.6	-	-

Summary of tests results of trajectory disturbances of pedestrians walking in the same direction – **tier 2**, in **full** perception condition and **suggesting** mode (FP-S-T2)

Configuration	P1 mean disturb.	P2 mean disturb.	P3 mean disturb.	SD of mean disturb.	Statistically significant	Effect size
1 vs. 2	54.0	58.6	-	3.3	-	-
1 vs. 3	74.3	82.7	120.5	24.6	-	-
2 vs. 2 north	158.3	73.2	-	60.2	Yes	d = 0.99
2 vs. 2 south	86.7	68.7	-	12.7	-	-

Summary of test results of trajectory disturbances of pedestrians walking in opposite direction – **tier 1**, in **limited** perception condition, and **highlighting** mode (LP-H-T1)

Configuration	North collective mean of disturbance	South collective mean of disturbance	SD of means disturbances	Statistically significant	Effect size
1 vs. 1	108.3	72.4	25.4	-	-
1 vs. 2	40.3	62.9	16.0	-	-
1 vs. 3	103.2	39.6	44.9	Yes	d = 1.13
2 vs. 2	44.7	110.6	46.6	Yes	d = 0.78

Summary of tests results of trajectory disturbances of pedestrians walking in the same direction – **tier 2**, in **limited** perception condition, and **highlighting** mode (LP-H-T2)

Configuration	P1 mean disturb.	P2 mean disturb.	P3 mean disturb.	SD of mean disturb.	Statistically significant	Effect size
1 vs. 2	72.5	53.3	-	13.6	-	-
1 vs. 3	33.7	35.6	49.3	8.5	-	-
2 vs. 2 north	28.3	61.0	-	23.1	Yes	d = 0.79
2 vs. 2 south	105.6	115.4	-	6.9	-	-

Summary of test results of trajectory disturbances of pedestrians walking in opposite direction – **tier 1**, **limited** perception condition and **suggesting** mode (LP-S-T1)

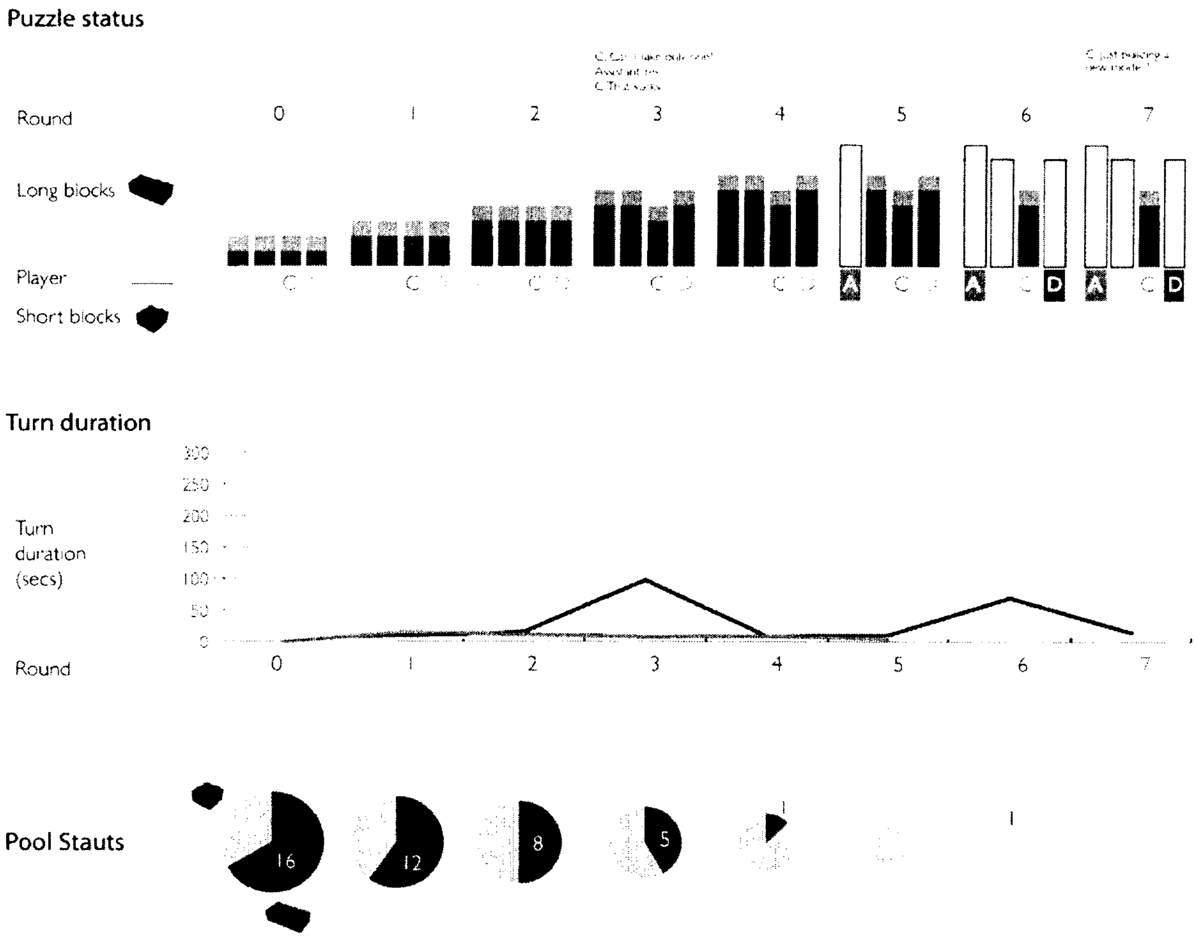
Configuration	North collective mean of disturbance	South collective mean of disturbance	SD of means disturbances	Statistically significant	Effect size
1 vs. 1	85.6	113.4	19.7	-	-
1 vs. 2	50.3	31.9	13.0	Yes	d = 0.5
1 vs. 3	20.91	74.1	37.6	Yes	d = 0.87
2 vs. 2	45.6	37.8	5.5	-	-

Summary of tests results of trajectory disturbances of pedestrians walking in the same direction – **tier 2**, in **limited** perception condition and **suggesting** mode (LP-S-T2)

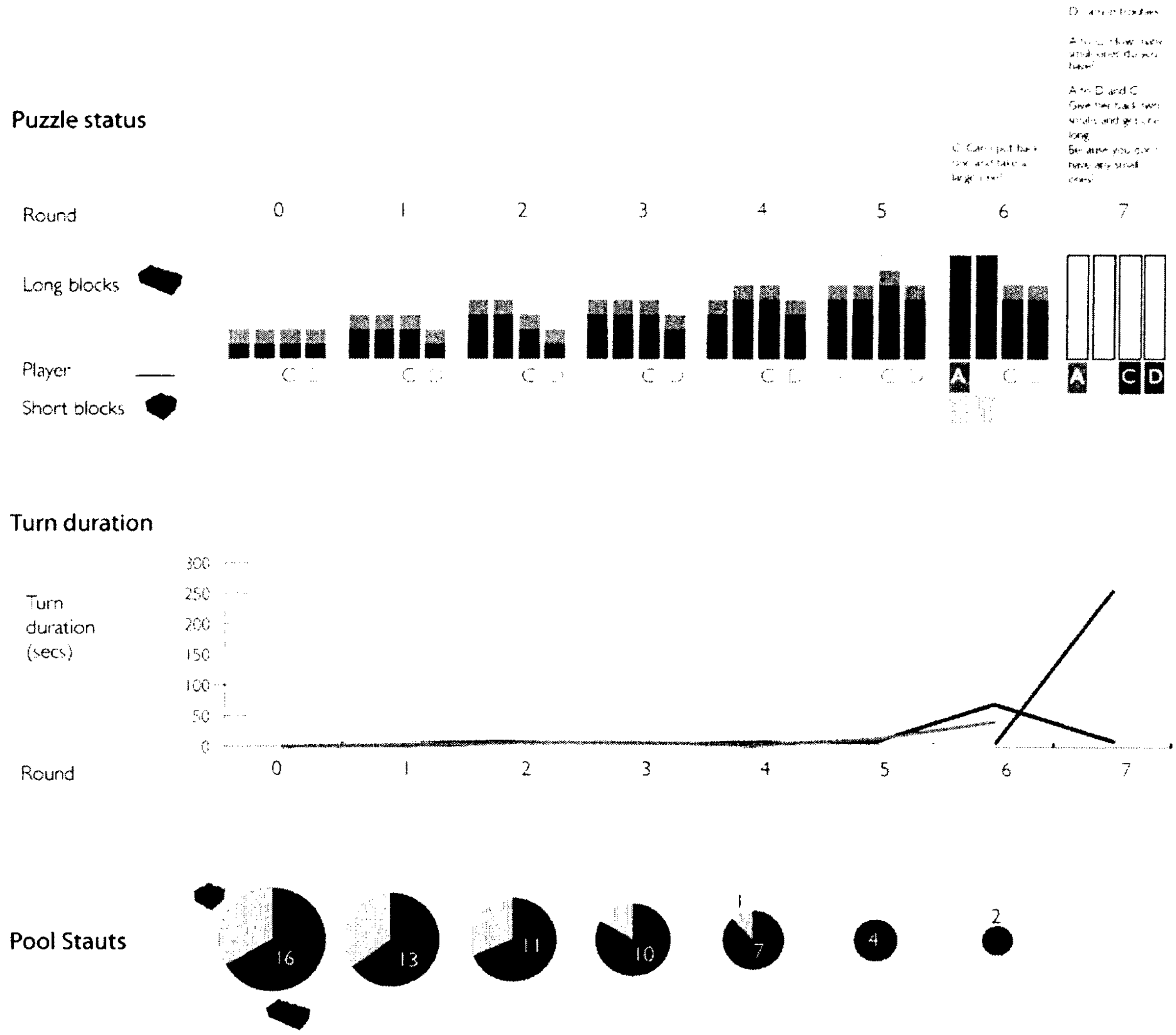
Configuration	P1 mean disturb.	P2 mean disturb.	P3 mean disturb.	SD of mean disturb.	Statistically significant	Effect size
1 vs. 2	42.1	76.0	-	24.0	Yes	d = 0.61
1 vs. 3	66.1	106.7	50.9	28.9	Yes	$eta^2 = 0.1$
2 vs. 2 north	48.5	42.6	-	4.2	-	-
2 vs. 2 south	36.1	39.4	-	2.4	-	-

APPENDIX C

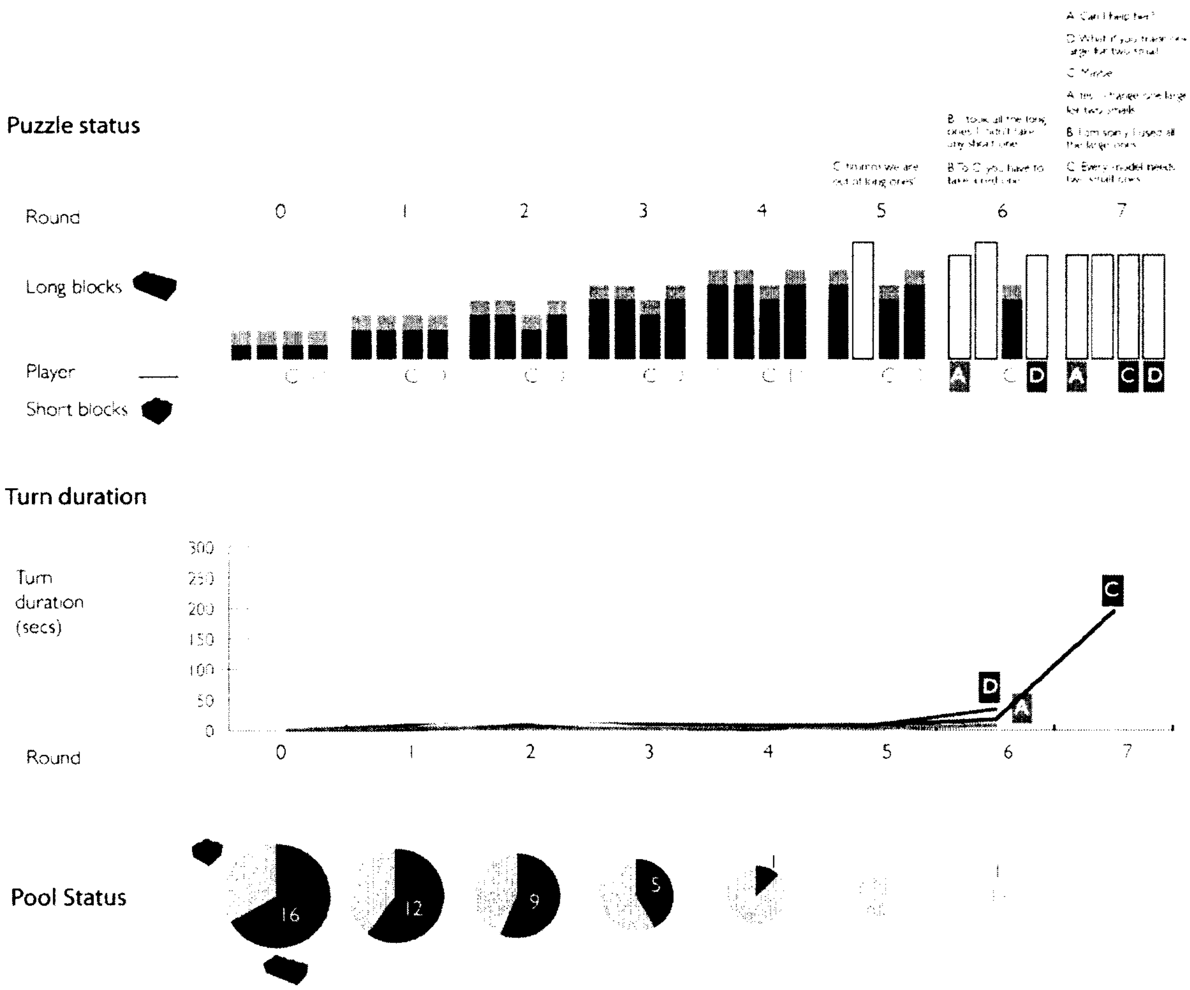
GAME EVOLUTION AT REGULAR AND SMART TABLES OF STUDY 2A



Study 2A. Game evolution of smart table 1 over rounds



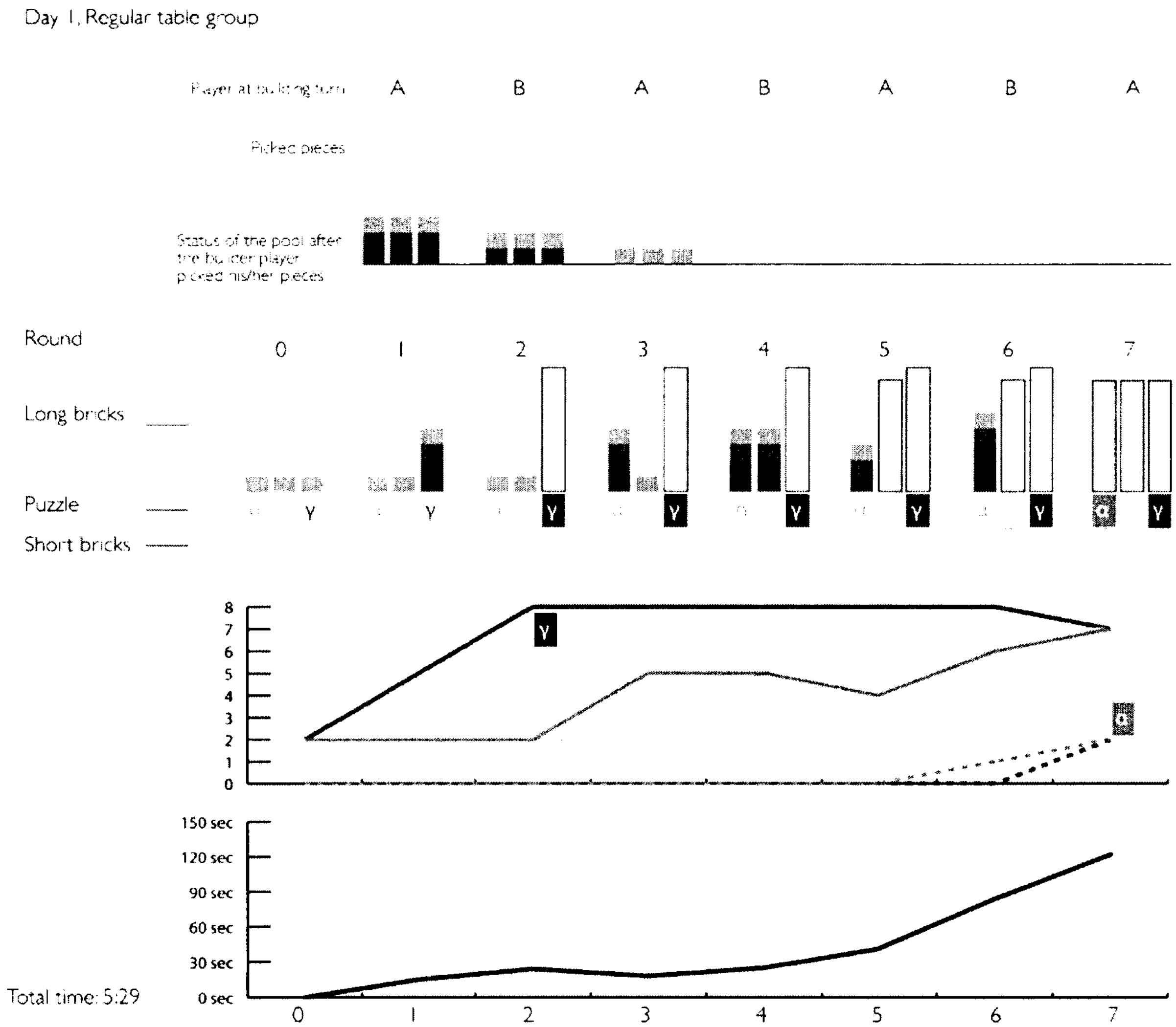
Study 2A. Game evolution of smart table 2 over rounds



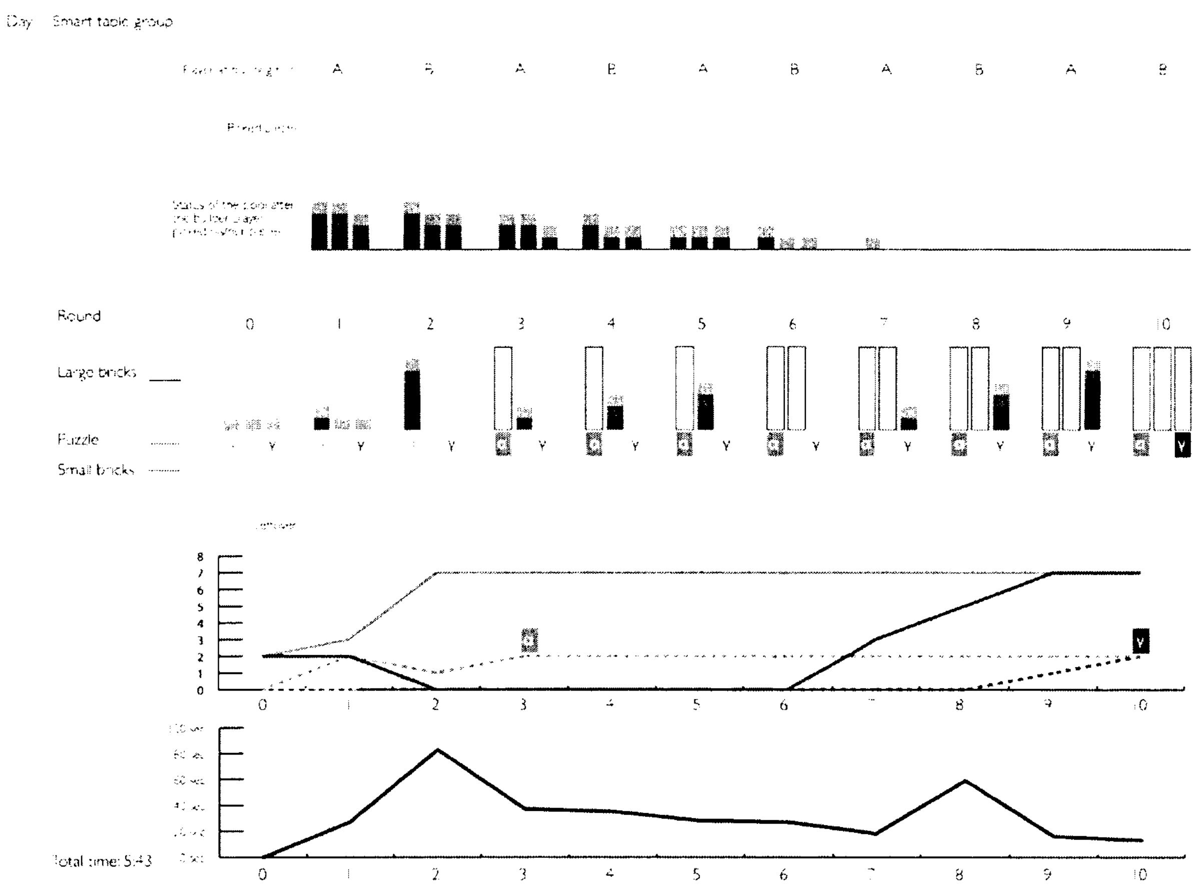
Study 2A. Game evolution of smart table 3 over rounds

APPENDIX D

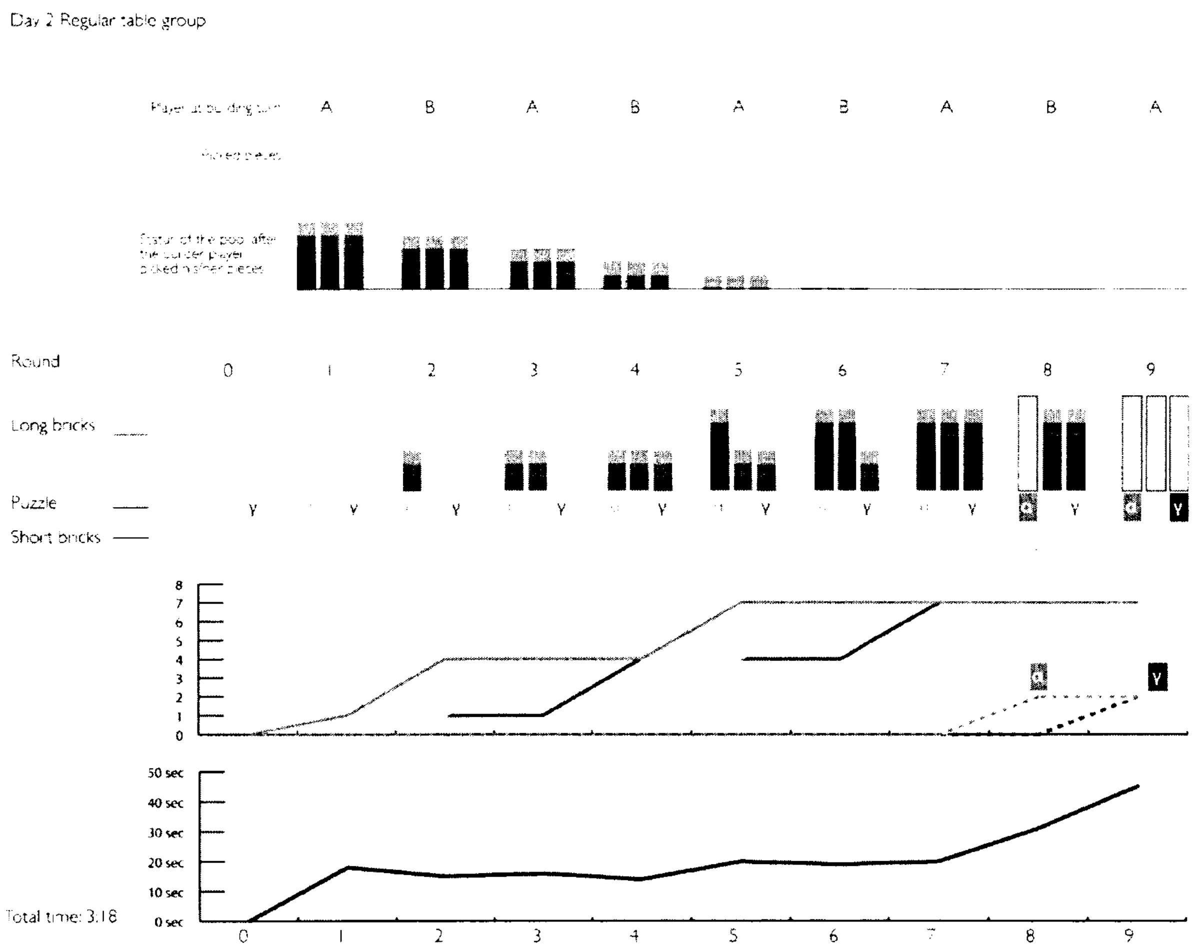
EVOLUTION OF IMBALANCES OF BUILDING BLOCKS AND TURN DURATION IN STUDY 2B



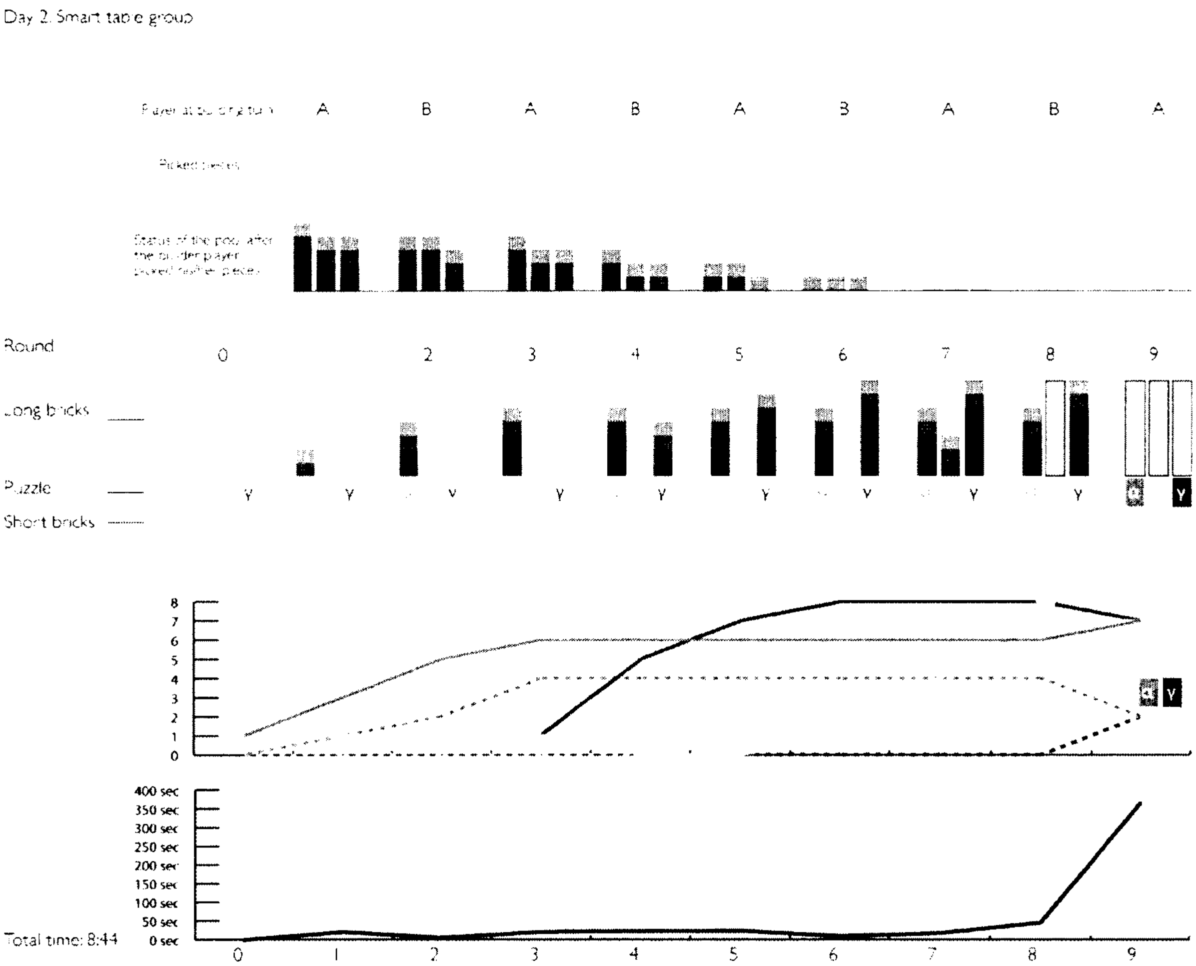
Study 2B. Evolution of imbalances of building blocks and turn duration at the **regular** table 1. Continuous colored lines represent the number of long blocks, dotted lines the amount of short blocks



Study 2B. Evolution of imbalances of building blocks and turn duration at the **smart** table 1. Continuous colored lines represent the number of long blocks, dotted lines the number of short blocks



Study 2B. Evolution of imbalances of building blocks and turn duration at the **regular** table 2. Continuous colored lines represent the number of long blocks, dotted lines the number of short blocks



Study 2B. Evolution of imbalances of building blocks and turn duration at the **smart** table. Continuous colored lines represent the number of long blocks, dotted lines the number of short blocks

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