Modeling socially apt smart artifacts

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ABSTRACT
Although smart artifacts could be designed as agents with whom humans interact, the resulting interaction between them is asymmetrical if the smart artifacts are designed solely to support the accomplishment of human plans and goals. The ontological asymmetry between both human and non-human agents prevents designers of smart artifacts to consider them as actual social actors capable of performing a social role instead of just being tools for human action. In order to overcome such asymmetry this research repositions smart artifacts as mediators of social interaction and introduces a triadic framework of analysis in which two interacting humans and a non-human agent are regarded as networked and symmetrical actors.

The implementation of the triadic framework in a staged study revealed that, in the achievement of personal goals, groups of people exhibit a social viscosity that hinders people's interactions. The mediation of purposely designed smart artifacts can reduce such social viscosity and facilitate cooperative and collaborative interactions between networked actors if they prompt the preservation of social balance, enhance the network's information integrity, and are located at the focus of activity.

Author Keywords
Interaction design; smart artifact; adaptive mediator; Actor-Network Theory; ubiquitous computing.

ACM Classification Keywords
H.5.m. Information interfaces and presentation: Miscellaneous; I.6.m. Simulation and Modeling: Miscellaneous; I.2.11. Artificial Intelligence: Intelligent agents.

INTRODUCTION
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. User-centered design (UCD), based on the humanist assumption that people have the control over computational systems, has been the dominant methodology for the design of human-computer interaction. Although UCD approaches remain useful for exploring how people cope with interactive systems [19], they cannot fully explain how such new breed of smart artifacts mediate people's social interaction. While UCD approaches assume that human agents control interactive systems, it disregards the potential for agency of smart artifacts [1]. Other theoretical frameworks better explain social interaction mediated by artifacts such as Distributed Cognition [9], Activity Theory [10], or Actor-Network Theory [14][12][13]. The ideas discussed in this paper adopt Actor-Network Theory (ANT) as their theoretical ground.

Post-humanist thinkers such as Callon[4], Law [14], Latour [12] and Knorr-Cetina [11] contend that we are increasingly living in an object-centered society where the roles of objects are not only defined as commodities or equipment but also as activity partakers. In that vein, smart artifacts could be defined as agents involved in social practices mediating and cohering both humans and other artifacts together. According to ANT, both humans and smart artifacts are social actors who can assemble hybrid social collectives while they interact with each other. This paper offers a triadic structure of networked social interaction as a methodological basis to investigate i) how collectives of humans and smart artifacts get assembled, ii) how smart artifacts could understand their social setting and finally iii) how smart artifacts adaptively mediate people's interactions within social activities.

A future scenario of smart urban mobility reveals the intertwinement of human and non-human actors. Let us picture pedestrians and drivers intermingling with smart artifacts such as smart vehicles, smart traffic lights, adaptive speed signs and intelligent crosswalks as they circulate, coordinate turns, allow traffic flow and control agent's speed. In this ecology of actors a smart traffic light, is not only a piece of urban equipment that regulates the flow of traffic, but a networked social mediator of a complex adaptive system. Instances of smart traffic signs can be observed today in the City of Seattle. The city's active traffic management system analyses real time traffic flow and signals the best speed to individual drivers via

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adaptive speed limit signs, aiming to procure the efficient flow of the whole community of commuters.

The goal of this paper is to present some considerations for the design of smart artifacts that can perform as social signifiers for the promotion of coordinated social interaction.

DEFINITION OF NETWORKED COLLECTIVES OF HUMANS AND SMART ARTIFACTS

A smart artifact is a scripted agent that autonomously acts in the world by adapting its own structure while preserving its organization. Smart artifacts are scripted with one or more programs-of-action by its designer. A *program-of-action* is a program of what an actor can do. As an example, a traffic light is smart if it interprets the dynamics of what drivers and pedestrians do and consequently adapts its timing to benefit people's flow preserving their integrity.

A *collective* is a hybrid social actor constituted when humans subscribe themselves to smart artifacts' programs-of-action. As an example, drivers constitute a collective with the smart traffic light (smartTL) if the former abide by the signals of the latter. The actions of the constituted collective are meaningful not only to pedestrians and drivers present at the collective's scope but to the whole network of actors participating in the practice of commuting.

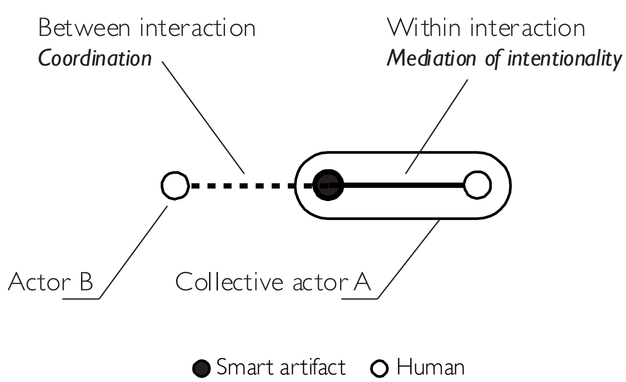

Figure 1. Triadic structure of networked social actors and its within and between interactions

This research offers a triadic structure of actors as a unit of analysis that accounts for the interactions within human-nonhuman collectives and between hybrid social actors in the actor-network. It is a triadic structure because it is composed at least of two interacting humans and one non-human agent. This triad is the basic unit of a network of symmetrical social actors. In order to exemplify within and between interactions let us picture the collective actor *A* in Figure 1 as the collective pedestrian- smartTL and the actor *B* as a car driver. The car driven by the driver is omitted in the example for simplification purposes. 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. In the case of the collective pedestrian- smartTL, the interactions of both agents sensing their proximity and mutually adapting their actions to the ongoing situation hold them together within the same collective. Moreover, a car driver does not interpret the actions of a pedestrian at the street corner just as a single walker wandering around but as a pedestrian whose intention is tightly related to the current status of the nearest traffic light. The pedestrian together with the smartTL constitute a signifier for car drivers.

The *between interactions* are the social interactions that occur between collectives and characterize the dominant socio-relational model of the actor-network [8]. There is no unified classification of social interactions. Conflict, negotiation, cooperation, violence are kinds of social interaction that might emerge between social actors. This research project is particularly interested in cooperation. The interaction between the collective pedestrian- smartTL and the driver usually ends up in coordinated turn taking because the interacting collectives require the same right of passage concurrently. Turn taking is a form of cooperation. In some countries the driver yields the right of passage to the pedestrian-smartTL. But in other countries this is not the case, the socio-relational model between drivers and pedestrians privileges vehicular traffic over walkers flow.

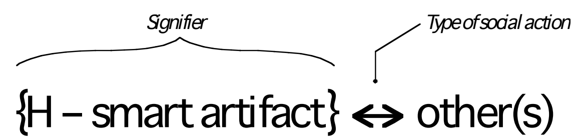

Figure 2. Notation of the triadic structure of networked social actors

Figure 2 presents a text-based form of notation of the triadic structure. The bracketed collective represents the *within* interaction and the arrow represents the *between* interaction.

As an example, {pedestrian-smartTL}→driver means that the social meaning of the collective {pedestrian-smartTL} is put forward for drivers as long as the collective persists. The within interaction of {pedestrian-smartTL} exhorts the regulation of driver's circulation flow. The between interaction corresponds to the coordination of passage between {pedestrians-smartTL} and drivers.

A NOTION OF AGENCY AND THE SYMMETRY OF ARTIFACTS AND HUMANS AS SOCIAL ACTORS

As surveyed by Bullington [3] the research on computational agency in social interaction has two major strands of research. On the one hand, we have the human-agent approach represented by the goal of the Turing test. Its object of concern is the socialization of humans with artificial agents [2][17][5]. On the other hand, the structuralist approach focused on the analysis of the structure of social groups that emerges from the inter-subjectivity of agents. Its object of concern is the bonding structures from which a collective of agents emerge and evolve [7][15].

ANT aligns with the latter approach. The symmetry proposed by ANT endows both human and nonhumans with the capacity for social action. Such symmetry does not reduce humans to mere objects, nor does it grant intentionality to objects. To be clear, symmetry does not have a geometrical meaning. The symmetry of social actors is an analytical viewpoint that positions people and objects as members of a social set without dichotomizing them. Under ANT, there is no hierarchy between human and nonhuman actors. Human and nonhumans are social actors that are placed on an equal footing, whose forms of actions simply differ. As Law puts it by drawing a distinction between ethics and sociology, the symmetry between human and nonhuman actors "is an analytical stance, not an ethical position" [14].

The fact that human and nonhuman actors are not dichotomized enables us to declare them as instances of the same class of behavioral agents. The main attribute of this class is embodiment, and the class' primary function is to react. *Behavioral social action* was described by Schutz as a reactive action triggered by external conditions [18]. *Proactive social action* as explained by Schutz is a complementary type of action, characterized as intentional and intrinsic to the acting agent. Simple artifacts are behavioral agents, but both smart artifacts and humans exhibit proactive action. Figure 3 depicts how the Proactive agent class inherits the embodiment attribute and reaction function from the Behavioral agent class, and extends its functions by implementing a higher-level function: to act.

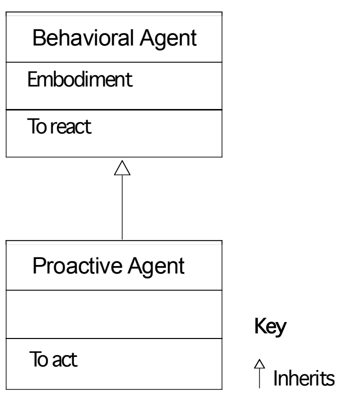

Figure 3. Class structure of behavioral and proactive agency

ANT does not claim that artifacts plan actions but rather they enact programs-of-actions. Albeit nonhuman agency appears to be a contradiction, it is systematically displayed in programs-of-action that involve the participation of artifacts [4]. In the case of humans, it is associated with their intentions. In the case of artifacts, it is associated with the criteria for social action inscribed by their designers. The significance of nonhuman action comes to light as artifacts "allow, afford, encourage, permit, suggest, influence, block, render possible, forbid […]" [13] states of affairs.

Going back to our scenario of smart urban mobility, SmartTLs could be scripted with a program-of-action that privileges pedestrians over manned and unmanned vehicles. Drivers are agents with their own behavioral and proactive programs-of-action. Table 1 presents a simplified description of the actors' programs-of-action.

Table 1. Example of behavioral and proactive programs-of-action

Agent	Type of program-of-action	Description of program-of-action
Smart Traffic light	Behavioral	Change light colors recursively
	Proactive	Privilege pedestrians flow and override behavioral program-of-action
Pedestrian	Behavioral	Avoid collisions while walking
	Proactive	Walk safely to his/her destination
Human driver	Behavioral	Abide by traffic rules
	Proactive	Drive safely to his/her destination

INTERPRETATION AND ACTION IN A SOCIAL SETTING

According to Schutz, the building blocks of an action are simple acts [18]. When an observer perceives an agent acting out its program-of-action some of its acts have been executed, whereas others are yet to be executed. The set of executed acts is referred to as *executed-program-of-action* (EPA), while the set of the yet-to-be-executed acts is referred to as *remaining-program-of-action* (RPA).

For example, Figure 3 presents the program-of-action of a person driving to a meeting composed of the following acts: A: get on the car, B: drive for ten blocks, C: park the car, D: get to the meeting on time. The RPA has a subjective meaning that is only known by the driver, i.e., no body knows where he/she is driving. In contrast, the EPA has an objective meaning because it has already been enacted in front of other agents including smart artifacts, i.e., he/she is driving somewhere. At the step *present time* in the time flow depicted in Figure 3, the EPA has an objective meaning for observers and smart artifacts, whereas the RPA has a subjective meaning known only by the driver.

By using Rough Set Theory [16] as a pattern finding technique this research proposes that smart artifacts can predict the remaining-program-of-action of human actors enrolled in a collective if the smart artifacts have a robust collection of their own executed-programs-of-action.

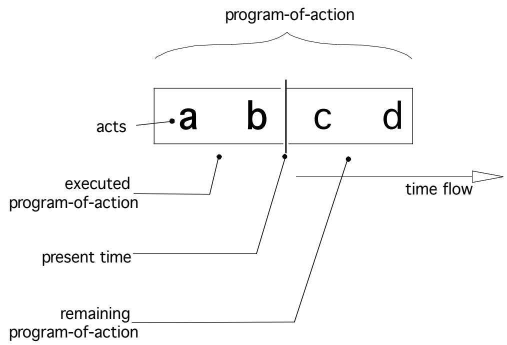

Figure 4. A program-of-action decomposed in single acts. The portion of the program-of-action enacted before the present time corresponds to the Executed program-of-action. The yet-to-be-executed portion corresponds to the Remaining program-of-action

In the execution of programs- of-action both human and nonhuman actors get intertwined and social dynamics emerge. While drivers drive, they must abide by the traffic rules reified as smart traffic lights. Concurrently, smart traffic lights adapt their timing as they sense the traffic and pedestrians approaching the intersection where they are located switching from red, to yellow, to green, accordingly and regulating the flow of traffic.

Going back to the driver's example, if at *present time* the smart traffic light turns red, it blocks the driver's action, delaying the execution of the driver's RPA – acts C and D. But, at the same time it enables the programs-of-action of pedestrians and other drivers who were waiting for their right of passage.

In ANT terms, when the actor's programs-of-action get intertwined, it is said that a human-nonhuman collective is composed. A network of collectives of behavioral and proactive agents therefore constitutes our notion of sociality. Such collectives emerge and dissolve themselves in the execution of their programs-of-action.

PROOF OF CONCEPT

An early analysis of pedestrians' trajectories in the wild revealed that it is possible to determine the subscription of actors to a crosswalk 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 crosswalk when his/her executed program-of-action is aligned to the intended direction of travel defined by the crosswalk design, i.e. walking straight across corners. In contrast, pedestrians are not subscribed when they exhibit trajectories other than the ones outlined by the crosswalk. For example, a walker wandering erratically on the crosswalk while he/she smokes a cigarette or talks over his/her mobile phone is not subscribed to the crosswalk's program-of-action. Subscribed and unsubscribed trajectories are both socially valid, but the former is prone to elicit cooperation or collaboration among walkers present on the crosswalk concurrently, whereas the latter can drive conflicting interactions.

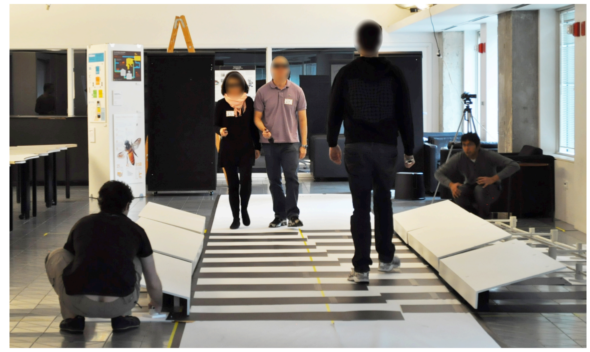

Figure 5. Wizard of Oz prototype of the study deployed at the laboratory

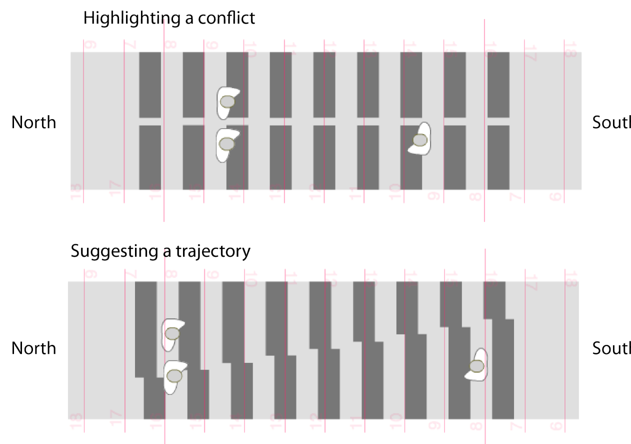

Figure 6. A smart crosswalk signaling forecasted conflicts to pedestrians

Study description

Based on the above observation, a smart crosswalk was designed and deployed in a laboratory. The smart crosswalk was scripted to dynamically signal the best distribution of the walking space among concurrent pedestrians. To do so, the crosswalk interprets the EPAs of each pedestrian and forecasts their RPAs. The assessment of multiple RPAs allows the crosswalk to identify potential conflicts in the ongoing social interaction and signals a suitable space distribution accordingly. The design tested in the laboratory consists of a striped pattern split along the north-south axis. Figure 6 shows the status of two distributions. The top illustration shows the halves of the striped pattern sliding sideways, the bottom one shows the result of the halves sliding both sideways and backwards.

Two smart crosswalks' signaling patterns were tested: i) highlighting a conflict of trajectories (Figure 6 top) and ii) suggesting trajectories to circumvent potential conflicts (Figure 6 bottom). The highlighting signaling pattern is intended to raise pedestrians' awareness to estimated trajectory conflicts. Such crosswalk's intervention is neutral because any potential trajectory negotiation is left to the concurrent group of pedestrians. The suggesting signaling pattern is intended to do a more active intervention because it suggests trajectory deviations to concurrent pedestrians biasing the outcome of any trajectory negotiation.

Sixteen subjects, selected from a pool of volunteers recruited by email on social networks, were asked to walk on both a smart crosswalk prototyped with the Wizard of Oz technique [6] and a staged regular crosswalk. Subjects were grouped in groups of up to three people. In a series of 10 runs, subjects randomly assigned to two groups located on both ends of the smart crosswalk were asked to walk from the north to south end of the crosswalk or vice versa. The data collected were: i) the pedestrians' trajectory at each step, ii) stride speed and iii) target accuracy.

Study observations

Overall, studies found that people walking on smart crosswalks have smaller trajectory deviations and higher target accuracy than people walking on regular crosswalks. However the walking flow of people on smart crosswalks slowed down. It appears that there was an inverse correlation between the trajectory disturbances and the walking speed. In other words, in order to walk fast pedestrians needed to sort out disturbances. Such disturbances were represented by the presence of other human actors enacting their own programs-of–action. The general observation is that pedestrians hinder the execution of each other's programs-of-action forcing themselves to constantly adapt or overwrite their original programs-of-action.

Analysis of observations and results

The following analysis applies the triadic model described above to the interaction of pedestrians mediated by the smart crosswalk. The two human actors of the triad are the pedestrian or group of pedestrians heading north (PHN) and the pedestrian or group of pedestrians heading south (PHS). These two actors are subscribed to the smart crosswalk as an instance of a nonhuman actor. The network of actors has two triads: *{PHN – smart crosswalk}* → *PHS* and *{PHS – smart crosswalk}* → *PHN*. The programs-of-action of both human and nonhuman actors in the network are presented in Table 2.

The within interaction of the collective *{PHN – smart crosswalk}* holds these two actors together, co-shaping the mediating meaning of a hybrid signifier. Such signifier is composed by the pattern signaled by the crosswalk and the actions of the pedestrians heading north on the smart crosswalk. The PHS actor interprets the signifier and adapts its actions accordingly. The between interaction of the triad can be observed in the dynamic negotiation of trajectories carried out by both groups of pedestrians circumventing potential collisions. Conversely, the complementary triad *{PHS – smart crosswalk}* → *PHN* has the same within and between interactions. Such networked triads constitute an adaptive system in which the modification of one actor's program-of-action affects the enaction of others' programs-of-action.

Table 2. Programs-of-action of pedestrians and smart crosswalk in the proof of concept study

Agent	Type of program-of-action	Description of program-of-action
Smart crosswalk	Behavioral	Afford pedestrians crossing from one end to the opposite
	Proactive	Either highlight potential conflicts or suggest trajectory deviations
Pedestrians heading north or south	Behavioral	Avoid collisions while walking
	Proactive	Walk to his/her/their destination preserving their clique's cohesiveness

The observations of the walking flow in both regular and smart crosswalks show that the within and between interactions have a double-edged effect in the actor-network. While the within interactions pull actors together, the between interactions offer resistance to the execution of the human actors' programs-of-action. As a result, people cooperate when they have conflicting programs-of-action or collaborate when they have aligned programs-of-action. Both cooperation and collaboration require that people coordinate their actions.

While smaller collectives coordinate easily, larger ones struggle to maintain coordination. The high trajectory disturbance observed in the study reveals the actor's friction enacting 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 such limited conditions when actions of smart artifacts have higher impact in the actor-network's viscosity and benefit communal action flow across the actors in the network. This research defines *social viscosity* 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.

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 smart artifact mediators improved human actors' degrees of coordination if such mediation i) prompts the preservation of social balance by enacting the dominant socio-relational principles, ii) enhances actor's information about the whole actor-network, and iii) is present at the focus of the social activity.

CONCLUSION

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.

Smart artifacts that put forward forecasted conflicts between networked human actors are prone to facilitate either kind of social interaction: cooperation or collaboration. Cooperation and collaboration are two types of social interaction akin to balanced forms of sociality.

Smart artifacts can be designed not only as tools that allow people to accomplish their tasks, but also as relational objects that step into social activity by suggesting actions that may benefit the whole community. As the example *{pedestrian – smart crosswalk} → pedestrian* shows, smart artifacts can act as signifiers of the social activity of a group of people and mediate forms of coordination between them. Cooperation is only one type of social action, however, the position offered here could be extended to other types of social action such as collaboration, conflict resolution or adhesion.

The design of socially apt smart artifacts demands that designers decompose social action by identifying the programs-of-action of all the interacting parties. The position discussed in this paper suggests a new role for smart artifact designers: the delineation of artifact's programs-of-action. By identifying potential triadic structures in the network of actors, and analyzing how action unfolds in each triad, designers can refine the social responsiveness of smart artifacts rendering them more socially apt.

Finally, social viscosity is the natural resistance of an actor-network to the fluidity of its actors' actions. It has a direct correlation to the size and density of the network.

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