Zia et al. Complex Adapt Syst Model (2016) 4:10
DOI 10.1186/s40294-016-0022-y

Complex Adaptive Systems Modeling

RESEARCH

Open Access

Impact of ICT-mediated collective awareness on urban mobility

Kashif Zia[1*], Alois Ferscha[2], Ahmad Din[3], Khurram Shahzad[4] and Awais Majeed[1]

*Correspondence: zia@bui.edu.pk
[1] Department of Software Engineering, Bahria University, Islamabad, Pakistan
Full list of author information is available at the end of the article

Abstract

Purpose: This paper studies the influence of information and communication technologies on human reasoning and decision making. It investigates the potential impact of ambient intelligence on change in pedestrian mobility behavior, using a large city-scale scenario.

Methods: This work establishes an interplay between social and technological aspects of awareness by augmenting a model-driven framework of a realistic information eco-system. A distributed multi-agent system is developed to model a real-life urban mobility environment. The model is then simulated using a large scale parallel computing platform.

Results: Evaluation results revealed that the quality of information in ambient-assisted environments increases when compared with those without ambient intelligence.

Conclusion: We conclude that there is a positive correlation between the extent of information being shared in a socially-inspired information eco-systems and the level of collective awareness in an urban mobility scenario.

Keywords: Behavioral change, Collective awareness, Large-scale pedestrian simulation, Multi-agent systems, Ambient intelligence

Background

Understanding the influence of Information and Communication Technologiess (ICTs) on humans' social behavior is an interesting and important research topic. "What behavioral change is expected in an ICT mediated society?", is one of the typical research questions, most widely explored (Mitleton-Kelly 2013). Reaction of people to innovation in general and the consequence of this reaction in relation with social analogies is discussed in (Straub 2009). It is observed that people trust on their abilities more as compared to those of the system (de Vries et al. 2003). However, it needs to be evaluated. In particular, the interplay between the notion of self and the ICT induced information towards awareness of phenomena of interest, is an interesting area to investigate. It becomes even more interesting in a scenario where a user is unwillingly influenced by its surrounding. However, it can only be achieved if the role of individual in a collective behavior is understood. Individual factors must be identified and linked-up to facilitate the emergence of a global norm (Ferscha 2014; Ferscha et al. 2012).

The evolution of the internet and social networks, devices and pervasive technologies, have enabled orchestration, aggregation, and mobilization of awareness and intelligence at different levels including collective awareness, collective judgment, and collective action and/or behavior change (Mulgan and Leadbeater 2013). Beside a steady advancement in technology, the need for solutions those are based on individual and collective awareness is further driven by the growing complexity and interdependence of modern societies and economies, suggesting "ideally" a planet wide collective awareness system (Giannotti et al. 2012). Independent from the scale in which such a collective awareness system is installed (e.g. a city, a country, a region, or the whole planet), the ambition should go beyond just the measurement and must be intended to create an awareness of the impact of human actions/decisions on the society (Giannotti et al. 2012). By creating virtual communities for social change and linking them with environmental monitoring to enhance their awareness, these collective awareness systems can be applied to effectively guide people in their everyday decisions, and reduce costs of decisions by optimizing them based on efficiency and ecological impacts (Sestini 2012). Some projects featuring the ubran mobility management are "SUNSET" (Bijlsma 2012), "Urban EcoMap" (Connected Urban Development 2013), "Who Owns My Neighbourhood?" (Thumbprint Co-operative 2016) and "Action for Happiness" (The Young Foundation 2016).

ICTs are capable of inducing the behavioral change in the communities and urban societies. However, there are conflicting views on the impact of ICTs on communities, divided across possibility of digital inclusion (Wellman and Haythornthwaite 2002) and digital divide (Stoll 1996). In either case, it is expected to induce behavioral change in the society (Ferlander 2003). Salah et al. (2011) argued that the ever-growing ubiquitous information provisioning in the society is capable of behavioral change in human subjects. They used the terminologies such as *source*, *message* and *recipient* to define roles that a technology can acquire to enable applications in the areas of positioning, feedback, messaging, evaluation and prediction. In Warschauer (2004), it is reported that such an application is often responsible of creating digital divide where willing participants take advantage of assistance being provided, whereas, reluctant participants stay at a bay. However, advocacy of seamless inclusion of technology in human day-to-day activities (Weiser 1999) persuades us to look beyond what is visible and argue based on inevitable. The technical systems (STSs) of the future will just be social systems, in which technology will be integrated seamlessly. Hence, a system of social collectives (even if it is enabled through pervasiveness of the technology) will be based on mutual benefit and collective well-being where the participants share information with the system as a consequence of benefit they receive due to human-to-system and human-to-human interaction. Hence, a technologically independent framework is required and is proposed in this research article.

At an individual's level, the basic catalyst of persuasion (towards a change in behavior, for example) has always been individual benefit. It can be as tangible as money and assets acquired by an individual, or as symbolic as cultural values and professional standing. However, in upcoming digital societies with potential information overload, the catalyst of persuasion will progressively be more social rather than individual. Towards this, relatively recent concepts of "social capital" and "social currency" in social sciences become relevant. The social capital defines and relates most factors convincingly valuable to investigate on extent of behavioral change in a society, namely, social network, social support, trust, and sense of local community.

In this paper, we investigate the mobility behavior of a large urban population as a consequence of collective awareness mediated by a city-scale information ecosystems. The goal of this study is to investigate the patterns of behavioral change of an urban population on the basis of information available about regional densities, ICT enabled information dispersion, and activity-driven pedestrian mobility. The change in an individual's behavior is then related to change in its activity/mobility plan during a city wide event, e.g. a festivity. A distributed multi-agent social capital model is developed and simulated. The proposed model describes how the value of social currency of an agent would evolve as it interacts with other agents and shares information. It also presents a quantitative collective awareness model to help support evaluation and interpretation of information available in the environment. This model of collective awareness lies in between social capital and agent perception model, incorporating the principles of social capital model within its own formulations. The collective awareness model is tightly coupled with the agent perception model for updating the decision parameters leading towards adaptation in agent mobility behavior.

The remaining of the article is organized as follows. "Related work" section presents the related work. The proposed models are presented in "The proposed model" section. The detailed evaluation results and associated discussion is carried out in "Evaluation and results" section. This article is ended with conclusion in "Conclusion" section.

Related work

The process of modeling an STS requires modeling each individual entity that constitute such a system. Such entities are typically heterogeneous and they posses different characters and capabilities. STSs are essentially large scale systems and they require numerous individual levels of interactions. It is, therefore, difficult to model such a system using structural or differential equations. On the other hand, the agent-based modeling (being an analytical method) is becoming popular to model social systems due to its capability of representing entities and their interactions (Gilbert and Troitzsch 2005). Simulating a large scale agent-based STS that is emphasized on crowd events is thus an interesting topic for researchers (Henein and White 2005).

Panou and Touliou (2010) have proposed a multi-modal route guidance for elderly and mobility impaired pedestrians that support the public transport operators in providing accessible services to the targeted group of pedestrians. They considered the walking distance and speed as crucial parameters in providing route guidance to mobility impaired pedestrians not only to use a particular transport service but also the allied facilities such as bus stations, hubs, and switching from one mode of transportation to another. Draghici et al. (2015) proposed the use of WiFi enabled devices such as smartphones and tablets to analyze human mobility in crowded situations such as festivals, sports events and concerts. These devices communicate with the WiFi Hotspots and routers installed at various places in the area and the data collected in this way are analyzed for pedestrian behavior. Vukadinovic et al. (2011) proposed an activity driven mobility model for theme park visitors to get a realistic mobility pattern to offer better services to the visitors. All these efforts are interesting and appreciable. However, their focus like other similar efforts have been on the technological side. As stated in previous section, our framework is technological independent, and provides a novel social perspective of ICT-mediated city-scale collective awareness.

The term STS originated from organizational structure and work force management (Trist 1981), however, it is currently in use in many domains [including urban activities (Valderrama and Jrgensen 2008)] that are based on both technical and social aspects (Fox 1995). In Fox (1995), Fox emphasizes the need to deal with "social" and "technical" aspects inter-dependently because "arrangements that are optimal for one may not be optimal for the other and trade-offs are often required". However, like many other STS studies, the focus of the study is only on organizational work flow. In Dauber et al. (2006) and Pan et al. (2007), the authors argued that individual and social behavior of most crowd agent models is unjustifiably oversimplified, inconsistent and incorrect. According to them, the development of a framework for human decision making and social interaction in emergency egress analysis, require more in depth consideration of social behavior.

For a socio-technical-urban-mobility simulation, more extensive and specific aspects are considered in this work. For the problem categorized as "ICT mediated collective awareness acting as a catalyst of change in pedestrian mobility behavioral", it integrates three categories of models (namely the social capital, collective awareness, and agent perception) which is itself a valuable contribution.

The motivation of social capital model is primarily theoretical. In order to develop a collective awareness model, the relationships of, agents with agents, and agents with environment based on physical, individual and informational aspects are important. To materialize this, we build upon the Focus/Nimbus (FN) awareness model (Benford et al. 1993), which was developed to address group awareness in a virtual and/or physical spaces. FN-Aspects Attributes and Resources (FN-AAR) (Metaxas and Markopoulos 2009) model is the most prominent extension of the original FN model, augmenting the original model with situation overlap in addition to the purely spatial overlap. This work has further extended the FN-AAR model according to our needs.

The simulation of a city-scale, fine-grained, agent-based evacuation itself is a valuable achievement. To the best of our knowledge, a cellular automata (CA) based city-scale evacuation simulation with hundred of thousands agents has not been attempted before. Many studies for large scale crowd simulation are conducted but they only focus on efficient simulation of agents and ignore the spatial dimension of the scenario (Solar et al. 2011; Perumalla et al. 2011). We believe that the spatial dimension is of high significance and must be considered in such scenarios.

The proposed model

Community effect and the social capital model

Social capital is defined in terms of resources accessed through social connections (Ferlander 2003). The term social capital is relatively new, however, similar concepts such as social isolation, social relations, and community, are in use in sociology for many decades (Tönnies 1957; Durkheim 1897; Masaryk 1909). According to Lin (2002), the above mentioned terms in combination with classical term of "community" captures the essence of the concept of social capital. The sense of community draws influence from connectivity, social values and trust (Kilpatrick et al. 2003) and creates a notion of belonging (culminating into mutual benefit) and responsibility towards the community (Jacobs 1961). This responsibility and crave for mutual benefit can push a person to perform social support and create social capital based on social relationships (Bourdieu 2008).

In addition to social relationships, the increase in social capital depends on the quality and usefulness of shared resources. Puntum (1995) provides the most comprehensive definition of social capital using all important concepts discussed above. According to him, it refers to features of social organization such as networks, norms, and social trust that facilitate co-ordination and co-operation for mutual benefit. It is analogous to notions of physical and human capital, in which tools and training enhance individual productivity (Putnam 1995). According to Puntum, norms have a reciprocal nature in which a supporter in a community is ultimately rewarded but not necessarily from the original beneficiary. Social trust must have confidence in trusting the information provided by the society even if the supporters are not known.

Based on the above mentioned theories and the basic formulation proposed in (Ferlander 2003), we believe that social network, support, and trust are the basic building blocks of social capital. The sense of local community is considered as an umbrella activity. The following four factors are used as design principles for developing our social capital model:

- *Volunteer support* means the social support provided by the individuals believing in social solidarity.
- *Mutual benefit* is the outcome of fulfilling responsibilities by the population and it must be enhanced.
- *Reward* given to the individuals believing in social solidarity.
- *Trust* of the population on individuals who believe in social solidarity.

Using these factors, this work proposes a realistic agent-based model of social capital by dividing the agents into two categories, namely social (depicting more social agents) and regular (depicting less social agents). This model also integrates the social capital model with the dynamics of behavioral change. We expect social agents to provide significant volunteer support in their locality. However, a regular agent is required to respect local community, and ensure mutual benefit by trusting a social agent and providing positive feedback. This would increase the *social currency* of social agents keeping them motivated for further social support. In return, the social agents are rewarded with context aware information, which is required for appropriate behavioral adaptation.

More concrete details of social capital model are presented below:

1. *Volunteer support* An agent must be a social agent to volunteer. It can act as a source of information, and volunteer its time and effort if it is well aware of the importance of social solidarity. A social agent can be beneficial at two levels of information sharing. Firstly, it may provide the information to the recipients that is most useful to itself. Secondly, it may provide the information to the recipients that is exclusively

useful to a recipient. The information in latter case, however, is not only very difficult to imagine (except some cases such as kinships and friendships) but it is also not social. In this work, we, therefore, model social agents with the capability that it provides information to the recipients that is useful to itself.

2. *Mutual benefit* Mutual benefit of the society is directly proportional to the attractiveness of the shared information. This information can be classified as the following:
   Most Attractive information is the information provided to a recipient that is exactly required by the recipient. For example, it happens when the source and recipient are moving towards the same destination.
   Attractive information is the information provided to a recipient that is useful but not immediately required by the recipient. For example, it happens when the information is not about current destination, but still a prospective destination in future.
   Not attractive information is the information provide to recipient that is not useful at all. For example, it happens when the information is neither about the current destination nor a prospective destination in future. Regular agents, in first two cases, are responsible of providing feedback about the source in terms of attractiveness of the information. Only social agents are allowed to volunteer and spread the information.
3. *Reward* Reward is repeatedly given to the social agents in terms of more useful (and currently required) information in return to volunteer services. This keep social agent contextually updated, and thus attentive and motivated to propagate the information.
4. *Trust* Trust is another parameter that has a major role to determine the usefulness of information in addition to the its attractiveness for a recipient. Trust may increase or decrease based on the inter-agent experience (either positive or negative) and the availability of same information from other sources. Trust has been used in many agent based models, however, we use Puntum's assumption, that a social agent trusts a piece of information provided by the source, even if the source is not known to it. It is believed that when an information is attractive, it is considered enough to trust it and hence its source.

The collective awareness model

The collective awareness model describes the interactions among agents on the basis of physical and individual aspects. It integrates social capital model within itself and provides decision support parameters to the mobility model described later. In an urban landscape, in which the population is possibly influenced by ambient assistance, an agent in the collective awareness model must consider the effect of three different types of interactions (that are agent-to-agent, agent-to-environment, and environment-to-agent) for the decision making process. The technologies used in these environments are categorized as either public or private. The technologies that are not exclusively owned by the agents such as displays are public. On the other hand, the technologies carried and exclusively owned by individuals such as smart phones comes in private domain.

The collective awareness model is based on the following assumptions:

1. Public displays are installed on selected places in the city and can be perceived visually. If the constraints imposed by visual range and line-of-sight are met, both social and regular agents are equally capable of using information being displayed.

2. Each agent has a smart phone capable of the following connections:

   a. Proximity based agent-to-agent connectivity: is from the social to regular agents in the vicinity using a technology such as Bluetooth (Haartsen 2000).
   b. Global system-to-agents (social) connectivity: is from the centralized system to the social agents using a technology such as mobile Internet (Kim et al. 2007).
   c. Global regular (agents)-to-system connectivity: is from the regular agents to the centralized system using a technology such as mobile Internet.

The city is divided into multiple sub-spaces and the global Internet connectivity of an agent, when applicable, is restricted to its own sub-space. The distribution of system into multiple information spaces is closer to reality and makes it easily manageable. Furthermore, it is more in-line with our distributed simulation environment.

The extended FN-AAR model

The FN-AAR model of spatial awareness (Metaxas and Markopoulos 2009) used the concepts of Nimbus and Focus to enable mutual awareness of entities in a group for a virtual environment. The *Nimbus* represents the sub-space across which an entity makes its activity/presence available to other entities. On the other hand, the *Focus* represents a sub-space within which an entity focuses its attention. In other words, the Focus of an entity i represents its own view while the Nimbus represents the view of the entity j about which i needs awareness. The extent of overlapping between the Focus of i and the Nimbus of j designates the level of awareness of i about j. In its simplest case, the nimbus of entity j can act as its focus and the focus of entity i can acts as its nimbus thus making j aware about i in a reciprocal fashion.

Figure 1 illustrates the possible negotiations between Foci and Nimbi of the interacting agents. The solid circular boundary (colored red) represents the visual range of the display at the center. The visual range together with the orientation (direction indicated by an arrow) and the attractiveness of the display defines the Nimbus of the display. Any person out of the visual range of the display (as in case of p_1), whatever its focus may be, would not be attentive towards the display. Within visual range of the display, the focus of a person is applicable. Adopting the interaction based on vision, if the display of a person is within the visual range of a person, the orientation of both player and display must be inline with each other. Otherwise, the person would not be attentive to the display (as in case of p_2 and p_3). On the other hand, if the orientations of both concides with each other, we get a successful "spatial/physical" overlap of Focus and Nimbus.

In FN-AAR model, the physical overlap of interacting agents is not sufficient to guarantee awareness. The situational overlap is also needed to achieve awareness. Person p_5 in Fig. 1 is attentive but p_4 is not, though both of them are physically overlapped with the display.

We in our earlier work (Ferscha et al. 2012), introduced the concept of "intense attention" to extend the FN-AAR model towards collective awareness. The proposed extension transforms this intense attention into a responsibility to perform an action (spreading information in this case). For example, the change in the behavior of the person p_5 from an observer to a source of information. The agents within the auditory range

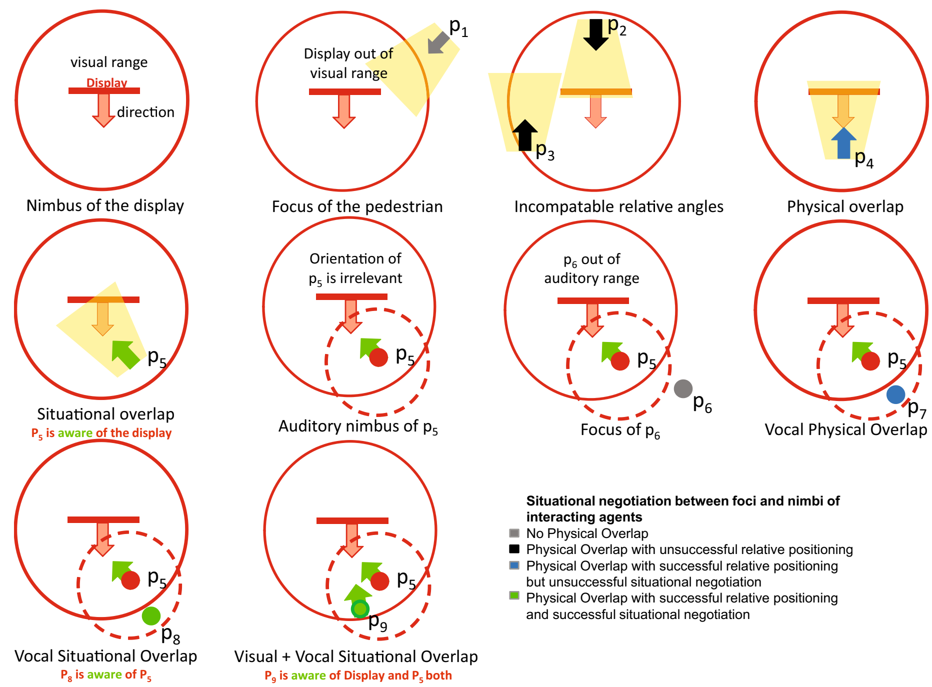

Fig. 1 Collective awareness model: negotiation between Foci and Nimbi of interacting agents

of p_5 represented by dashed circle (colored red) are potential recipients of this information. However, they may (as in case of p_8) or may not (as in case of p_7) get attention of p_5 based on individual's situation. If a person is out of the physical Nimbus of p_5, it would not be attentive as usual (as in case of p_6). Further, a person may have both visual and vocal situational overlap at the same time (as in case of p_9).

Aspects, attributes and resources in the extended model

The FN-AAR model is based on the following concepts (Metaxas and Markopoulos 2009):

1. *Entities* represent the actors/agents which may or may not need to be awared about a situation.
2. *Aspects* define characteristics of an entity and each aspect has certain role/meaning in the awareness model.
3. *Attributes* represent the state of an aspect. The entities provide information about their states using attributes.
4. *Resources* are mechanisms of announcing/displaying about attributes of entities.
5. *Observable items* are the results of displaying resources.

It introduced two concepts termed as *attribute-providers* and *resource-providers* to ensure that the attributes and resources are available dynamically. The attribute-providers populate the Nimbus and the resource-providers populate the Focus of an entity in certain situations. The reciprocal *Foci* and *Nimbi* of the two interacting entities, thus obtained using these providers, are negotiated through functions which produces observable items. The observable items are then used to designate the level of awareness between the interacting entities.

Before, we describe our model, it is needed to clarify the difference between attention and awareness. This work considers awareness as the main ingredient of attention. However, it is important to note that an entity being *aware* of a display does not mean that it is also paying *attention* to it. Attention requires follow-up actions which are not actually required when someone is only aware of some information. Fortunately, this classification supports the agent types, we defined earlier for this work. This work considers a social agent that is always attentive and a regular agent that is possibly aware of a situation. However, for model specifications, the difference between awareness and attention has no significance (and can be used interchangeably), as attention just adds action to awareness which is embedded in description of the agents.

The proposed collective awareness model is based on the above mentioned concepts with the following descriptions:

Entities and related aspects In the context of urban mobility, two types of entities are defined that are displays and persons. Person may be either a social or a regular agent. *Location*, *orientation* and *attractiveness* are common aspects of both the entities. The value of attractiveness is calculated based on the received information and how useful is this information. The rest of the aspects mostly based on mobility and interactions are associated only with persons. *Interest* defines how interested a person is about gaining information (more social, more interested). *Attention* defines the collective attention index of the person as a consequence of situational manipulations.

Attribute providers Each attribute provided by the functions is preceded with a "Display" and "Person" to distinguish its type. The attributes related to the displays during person-to-display interaction are described below:

1. DisplayLocation: which provides the location of a display.
2. DisplayOrientation: which provides the orientation of a display.
3. DisplayInformation: which provides the information content c currently displayed on a display.

The attributes related to the persons during person-to-person interaction are explained below:

1. PersonLocation: which provides the location of a person.
2. PersonInfo: which provides the information content c shared by a person.
3. PersonWillingnessToShare: which represents the willingness of a source person p_i to share the information with the recipient person p_j. The value of PersonWillingnessToShare attribute is based on type and attention index of person p_i. If the attention index value is greater than or equal to 0.5 (the threshold value), the information has gained enough of p_i's attention and it may be shared. Otherwise, the information is not shared. Using the agent type restricts a regular agent from sharing the information even if its attention index is more than the threshold.

Resource providers Resource providers are functions that provide the Focus of the entities which are typically persons in this work. During person-to-display and person-to-person interactions, a person uses its attributes such as *PersonInterest*, *PersonType*, *PersonLocation* and *PersonOrientation* to negotiate with Nimbus of the interacting entities. The *PersonOrientation*, however, is not required as Nimbus of a person in person-to-person interaction because it is not orientation dependent.

Observable items/combined functions These are the functions that provide results of negotiations between the Foci and Nimbi of interacting entities:

1. *DisplayInRange* function combines the Focus of a person (p_i) with Nimbus of a display and report the presence of display within the visual range of p_i. It considers the values of two functions namely DisplaywithinVisualDistance (that determines if display is within the visual distance of p_i) and PersonDisplayOrientationsCoincidance (it determines the coincidance of relative orientations of display and p_i), and returns true if both the values are true, but false otherwise.
2. *DisplayPersonCoincidance* uses the values of *DisplayInRange* and *InformationRepitition* to determine if the display and the person (p_i) coincides each others or not. It yields a true value if the display is in range and the "same" information is not received from the display earlier.
3. *PersonInRange* function combines the Focus of a person (p_i) with the Nimbus of another person (p_j) to report the presence of (p_j) within the *interaction* range of (p_i).
4. *PersonPersonCoincidance* returns a value true if a person p_j that is in range of person p_i is willing to share information with it and the information being shared is not already shared. This function return, false, otherwise.
5. *DisplayAttractivenss_c/PersonAttractivenss_c* The attractiveness of information content *c* being provided/shared is based on the extent of usefulness of the *c*, categorized as:

    a. The attractiveness of the information *c* is set to 1.0 (the maximum possible value to allocate), if it is exactly about the destination where the person is heading to.
    b. The attractiveness of the information *c* is set to 0.6, if it is not about the destination where the person is heading to, but included in his future plan.
    c. The attractiveness of the information *c* is set to 0.0 (the minimum possible value to allocate), if it is neither about the current destination where the person is heading to nor it is in the future plan.

Agents update formulations

The following actions are taken as a consequence of a situation:

1. *Attention update* is carried out in two different situations:

    - *DisplayPersonInteraction* when a person p_i and a display coincides, that is when *DisplayPersonCoincidance* function returns a *true* value.
    - *PersonPersonInteraction* when a person p_i and another person p_j coincides, that is when *PersonPersonCoincidance* function returns a *true* value.

- In both cases, the attention index value is updated based on the values of *Interest*, and the extent of *Attractiveness* of information content *c* being displayed/shared. Equation 1 is used to calculate this index.

$$Attention_i = Attention_i + (Interest \times Attractiveness_c) \tag{1}$$

The $Attractiveness_c$ value comes from a set of values comprises of 1.0, 0.6 and 0.0. An *Interest* value of 1.0 is assigned to social but 0.5 to regular agents.

2. *Social currency update* The social currency value of the source is also updated, if the attention index is increased. The increase in social currency value is proportional to the level of attractiveness of the information provided by the source. This update is carried out using the Eq. 2.

$$Currency_{source} = Currency_{source} + Attractiveness_c \tag{2}$$

Collective attention integrated with principles of social capital

The model of collective awareness is designed in a way that it facilitates agents to keep their role intact. It means that a social agent remains attentive and responsible to share the information in its proximity. On the other hand, a regular agent just receives the information and increments its awareness index as a result of receiving the information.

The first aspect that the proposed model handles is about space, and it investigates about the interaction between the display and a person (either social or regular in nature), as well as, a person with another person. The first case checks only a physical dimension, but the second aspect is also dependent on willingness of the source for sharing the information. The willingness is determined for a social agent based on the attention index (when it exceeds a threshold value). The dispersion of information in this work is initiated from displays and shared by the social agents only.

A social agent updates its attention index for information *c* based on its attractiveness and interest while interacting with a display. If the agents' attention for the information *c* is high enough, it decides to exclusively share this information with regular agents in its range. In response to this, the attention index of regular agents for information *c* may increase along with incrementing the social currency of social agents who are assisting them. The increase in social currency of individual social agents would increase the cumulative social capital of the society of the agents. Social agents are rewarded and thus the quality of information is greatly improved.

The agent perception model

This model comprises of two sub-models described below.

The agent memory model

The agent memory model employed in this article is derived from (Sperling 1967). The memory about an information content *c*, at a given instance, has a chance of either refreshing or fading. The memory is refreshed to a maximum value of 1.0, whenever, an attractive information is received or observed for the first time or in repetition. On the other hand, memory fading is dependent on a constant decrement (represented as *k*) and a variable memory refresh rate (represented as r). Memory fading is calculated using Eq. 3.

$$memory_{c[t]} = memory_{c[t-1]} - (k \times r) \tag{3}$$

The variable $memory_{c[t]}$ in Eq. 3 represents the memory of information c at time t (the current value to calculate in this iteration). The variable $memory_{c[t-1]}$ provides the memory about c at time $t-1$ (the value calculated in previous iteration). The value of k is dependent on the rate of forgetting about the information and it can be derived either from the biological or neurological studies. For example, if we set $\mathrm{k} = 0.1$ for an agent, it would forget about a piece of information in 10 iterations (each iteration represents a unit of time in our work). However, repeated reminders about the information may decrease the rate of forgetting it. This is represented as a variable r and calculated using Eq. 4.

$$r = (t_0 - t_r)/l \tag{4}$$

The variable t_0 in Eq. 4 represents the current time, and t_r provides the time at which the memory about c was last refreshed. The constant l represents the time in which memory about an information would vanish completely. For example, if $\mathrm{k} = 0.1$, then, the value of l would be 10. In this case, Eq. 4 resumes computing new values based on a refresh. In all other cases, Eq. 3 would use the previously calculated value of r until the difference between t_0 and t_r remains less than l. However, when this difference is greater than or equal to l, then, the default value of 1.0 for the variable r would be used.

The space and mobility model

The mobility model adopted in this work is categorized as an urban pedestrian mobility model. Usually, two ways are used to build such a model (Vogt et al. 2012). The first method extrapolates a generative model based on tracing real humans. The second method builds a model based on the lessons learned from a survey that is conducted prior the development of the model. In our case, we adopted the second approach in which the locations of interest (called Point of Attraction (PoA)) are first defined manually (Hsu et al. 2005), and then mapped on the physical space (Kim et al. 2009). PoAs were selected manually based on the demographic and spatial features of the city. The capability of our work to use high resolution (1.25 m^2 cells) grid size of the map enabled us to generate floor field at cell level. It eliminates the need of run time use of a microscopic level path finding algorithm (Vogt et al. 2012) which is a computationally intensive task. Moreover, it is not needed to annotate and link all the map as in (Vogt et al. 2012) as this work relies on raster's ASCII codes for the automatic detection of buildings and pathways.

In this work, the city is divided into center, urban, and outskirts. Displays are mostly located in center and urban areas. The PoAs are distributed across the city as shown in Fig. 2.

The proposed mobility model is materialized in the following two phases:

1. *Generating the agent plan* at start, the population (agents) is randomly distributed across the available space, i.e. the whole city in this case. Each agent initializes its plan with a randomly selected PoA using a probability of 50 % for the center and 25 % each for urban and outskirts areas. This initially chosen PoA is designated as P_0 and

Fig. 2 Simulation scenario. Center (enclosed in *red*) and Urban (enclosed in *blue*) areas are bounded while the Outskirts is not bounded. The displays installed at bus/tram stops are enclosed in *yellow* covering the Center in total and Urban area in partial. The PoAs are distributed across the three areas (6 in the Center, 3 in the Urban and 3 in the Outskirts of the city) and they are annotated with their corresponding region number

this would be the least "plan", an agent has to execute. Starting from P_0, an agent uses the probabilities given a transition matrix (as in Table 1) to select more PoAs based on current area. Within an area, the PoAs are chosen according to predefined preferences. An agent plan contains a maximum of half of the total points of interests.

2. *Plan execution* based on types of agents', the execution is carried out as follows:

   a. *Without social agents* as a base case, we can run a simulation in which agents execute their plan visiting PoAs one after the other. In this scenario, there is no assistance available to the agents, both public and private. Given that the agents are able to extract the information provided by the floor field, a step-by-step execution of the plan based on Euclidean distance would be straight forward.
   b. *With social agents* with displays installed in the city, the population would be affected by the information that is being provided there. A display would display density information of one PoAs (region *g*) which would be chosen randomly. Display would keep changing the PoAs after specified time.

Each person (social or regular) executes the attention and currency update mechanisms followed by mechanisms for making decision, updating memory, resetting density and granting reward. The update memory mechanism is explained earlier. The others are explained below:

1. *Making decision* When an agent receives density information, it changes the preference list of its plan. The mobility is, therefore, density dependent. With fading memory in practice, it is difficult for regular agents to receive new information and, thus, they are unable to change their course of action. On the other hands, social agents are capable of changing their preferences more frequently and they help regular agents to keep memorizing the density information. The regular agents reciprocate this favor by increasing their social currency in a hope that the information provided to social agents is also relevant to them. In fact, the information that is important for a source may also be important for a social agent has high probability of being important for regular agents in the proximity due to regional considerations outlined earlier. However, the agents make decisions irrespective of the valuation of the density information. In case, the information about a region doesn't exist or it has faded out from the memory, an agent would consider density in the proximity as density of that region.
2. *Resetting density* The densities at the destinations in the plan which are not yet visited, are set to density in the proximity, if $memory_g = 0$.
3. *Granting reward* Social agents are further assisted depending on the social currency they have earned so far. Agents with more social currency would be provided with information appropriate for current context (the currently destined PoA).

Table 1 Transition matrix: the propabilities for PoA selection

Area	Probabilities for PoA selection (%)		
	Centre	Urban	Outskirts
Centre	0.7	0.2	0.1
Urban	0.5	0.3	0.2
Outskirts	0.4	0.4	0.2

Model validation

The consideration of model validation is described in this section. The category of models having a sound underpinning on theoretical understanding are not validated. Hence, the theoretical concepts described against social capital and memory model are transformed into agents' behavior and integrated in the overall model. The other models have been validated in the previous work, of our own or from others. For example, the basics of awareness model are experimentally validated in Benford et al. (1993) and Metaxas and Markopoulos (2009). We in this work extended the model, introducing new aspects and attributes. We conceive that the newly introduced features are in-line with the original behavioral considerations. Nevertheless, the extended model can be validated in a real setting to authenticate it. However, this remains as the topic of future work from our perspective.

The space model is based on real map and data. The mobility model consists of two sub-models. The decision-making model (the agents choosing a PoA from a set of possible PoAs) have an underpinning on the notion of agents being rational in nature, thus, including the regional densities as the decision-making yardstick, and excluding other possible motives, such as, history/experience, preferences and emotions. However, the locomotion model (the next step decision and obstacle avoidance) draws motivation from empirical evidence reported in our previous work (Ferscha and Zia 2009). As far as the validation of the simulation results itself is concerned, it remains as our future work due to its complexity and practical limitations of the scenario.

Evaluation and results

Simulation environment

To simulate a large-scale agent based model, the most traditional way is to distribute it across a set of processors. If the agents need explicit and tight integration with the underlying space, for example, CA, the parallel and distributed simulation (PDS) using a shared memory multi-processor infrastructure provides a natural choice. CA provides a natural mechanism of space distribution across the processors in a regular grid style (Li et al. 2010). The repast-high performance computing (HPC) simulation tool (Collier 2010) provides built-in mechanisms of distributing a regular space into a set of uniform processing units. The processes are then synchronized through shared memory model.

The original map (with rough dimensions of 10,000 $\times$ 15,000 cells where each cell is of 1.25 m $\times$ 1.25 m) is incorporated into the proposed city model after dividing the original file into partitions. This work focuses on more interesting central region of the city as shown in Fig. 3a. The space thus selected comprises of 5000 $\times$ 10,000 cells, and it is divided into 200 regions (Fig. 2). Each region is a map distribution unit for parallel execution and it (the corresponding process of a region) is assigned to a dedicated processor. These regions are numbered from 0 to 199 and arranged in 20 rows and 10 columns. Each process is responsible to simulate a region comprises of 500 $\times$ 500 cells (Fig. 3b). To perform an activity such as a movement, the agents on top of cells utilize the spatial information to recognize the morphological features of the space underneath them (which include streets, obstacles and displays).

Since the whole space is distributed among independent processes, information synchronization is provided that must be invoked by these processes whenever it is needed.

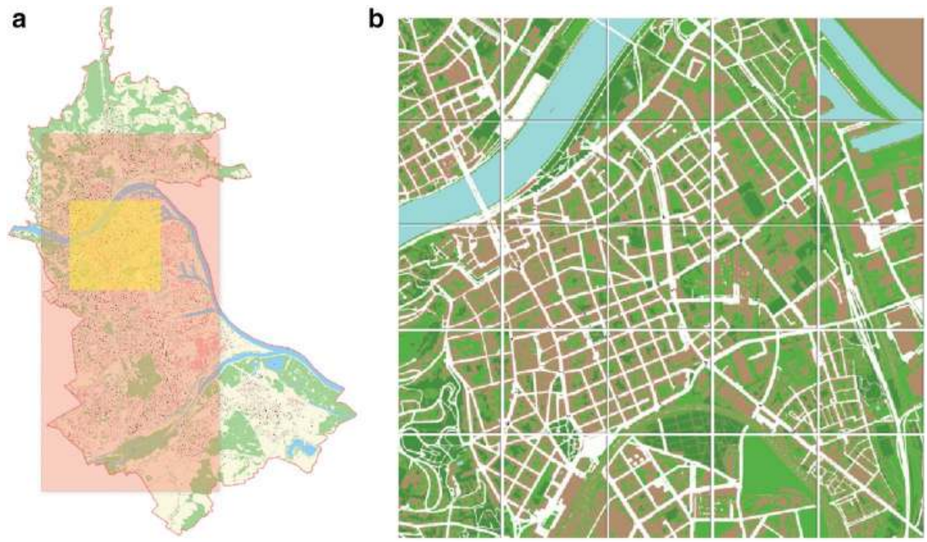

Fig. 3 Space distribution across processors. **a** The simulation space (shown in *pink*) and the media equipped city space (shown in *yellow*). **b** Regional view of the media equipped city space distributed across 25 processors. The *white* cells represent areas available where agents can move

The synchronization of processes across the boundaries in our case, where a space is represented as a cells based spatial grid, is achieved by specifying a buffered region of a certain size. The information stored in this buffered region are shared with the processes requiring them to achieve spatial synchronization. The agents in the buffered region are also synchronized and they share this synchronized state to the neighboring process whenever required (possibly as a proximity of an agent). When an agent moves from one process to another, an existence of the agent is created in the new process and the old existence is removed from the old process.

Repast- HPC provides "buffer" sharing mechanism across adjacent processes, which is parametrized by the neighborhood type and the size of the buffer (see Fig. 4a). During the Floor Field (FF) spreading, originating from each PoA, a buffer size of "1" is sufficient. However, for an agent's local mobility, a buffer size of "2" was required in our case. In addition of space and agents being buffered across adjacent processes, they can also be "networked" (see Fig. 4a); however, through inter-process information sharing.

Figure 2 shows a set of PoAs defined in this work which attract agents towards them. Each agent moves towards one PoA at a given time. An agent extracts its routing information from the underlying cells (spread from PoA using FF method (Kirchner and Schadschneider 2002) during simulation initialization). The FF method provides the direction, distance(hop count), and route(series of regions constituting the path towards a PoA) information to the agents. In case of mobility, an agent chooses a PoA which has minimum traveling time towards it. The speed, that is counted towards PoA selection, is dependent on density along the selected route.

An agent needs to sense its surrounding, and interact with other agents in the proximity, for determining a routing decision. It then executes a decision based on FF and neighborhood information. Further, an agent needs to know the states of all the cells where it has a possibility to move to them in upcoming iterations. Moore's neighborhood (Kretz

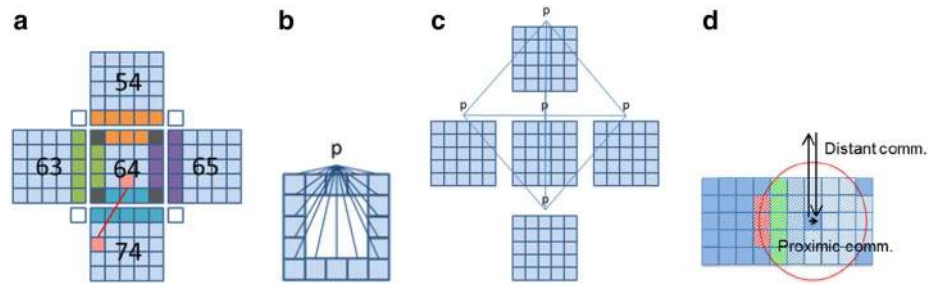

Fig. 4 Data sharing across the processes. **a** 4 out of 8 adjacent processes of process 64 with buffer size =1. Cells in *gray* are being shared across more than one process. Adjacent processes also provide Network Synchronization (A2A in *red*). **b** Process level parameters: can be collected and shared by all the resources of the process. **c** Inter-process parameters sharing: not supported by repast-HPC; responsibility of all the processors to act on agents' behalf. **d** Proximic communication of radius 3 (*red colored circle* of agent at the center). Enabled buffer synchronization across adjacent process (*green*), disabled sync. across adjacent process (*red*). Also shows channels of inter-process distant communication

and Schreckenberg 2005) is used for this purpose. In addition to proximity communication, Repast- HPC also provides "process-specific" data sharing (illustrated in Fig. 4b) and inter-process data sharing (illustrated in Fig. 4c). In our current model, we do not require process level parameters, as agent behavior is completely localized. However, the Agent-to-Agent (A2A) distant communication (explained in Fig. 4d) cannot be achieved without processors taking responsibility of sharing information with remote processors.

Scenario setup

We created a population of 120,000 agents, and they were distributed in available spaces (the area representing streets) across the regions. This automatically ensures a denser population in the central region of the city due to denser transport network. The simulation was run for 10,000 iterations (where 1 iteration = 1 s). The public media equipped living spaces (such as those at bus stops and tram stations) of the city were populated with spatial features representing public displays (Ferscha et al. 2012). The bus stops and tram stations were identified through Google maps and they were then incorporated into the model. 25 central regions out of the total 200 regions were displays rich area in which we identified 197 public displays.

The agents were initialized at random locations without physical overlaps. In those cases, where the agents encountered with mobility constraints due to obstacles or other agents, they acquired a locomotion with local deviations (Ferscha and Zia 2009). The agents were allowed to interact with displays and other agents within the desired radius based on the specifications of the models described earlier in this paper.

The following scenarios (cases) were simulated:

1. *Case 1: no information sharing* In this case, the only information available to the agent is the density of its own region (process). This known density would be considered as the density of all regions including the one holding the PoA in the city. Since, the decision of preference for a PoA is dependent on its regional density, and the information about all the PoAs is exactly the same in this case, there would be no

change in original activity plan of the agents. Hence, this case serves well as the base case.

2. *Case 2: information sharing through displays only* In this case, the information is spread through displays only. Hence, a person paying attention to the display's contents can be benefited, as long as the information being displayed is useful (corresponds to his activity plan). However, the chances of information being useful are less because the information is displayed at random.
3. *Case 3: information sharing through displays and distant person-to-person calls* In this case, the information is shared through displays and distant person-to-person calls. Only the social agents (persons) are capable of bi-directional interaction with each other. The regular agents can only be influenced by publicly available information via displays as before.
4. *Case 4: information sharing through public displays, person-to-person vocal communication, person-to-person calls and social capital rewarding* In this case, the information is shared through displays and proximic person-to-person interaction with model of social capital. In the presence of both public and private information units, the random person-to-display and context-aware person-to-person PoA information would augment the agent's information quality in terms of attention and memory. The interactions with agents are handled by social capital and collective attention model.

Simulation results

In the simulation, conducted during this work, 7 out of 12 PoAs were used by the people. Each agent's plan consisted of 1–6 PoAs. Many agents started in the outskirts of the city, and they adopted the PoA labeled, 6, due to its preference over PoAs labeled 178, and 153. Even the agents from outskirts of lower half of the city took, 6, as the first PoA to visit. They were about 50 % of the total population (57,300 out of 1,20,000 in numbers). In center, the PoA labeled, 33, has more preference over the rest of the 5 PoAs, which attracted around 52,300 agents. The rest of the agents preferred to start their plans with the PoA labeled, 4, in the urban area. However, these agents are not more than 10 % of the total population.

Quantitative analysis

Figure 5 provides evaluation results of all PoAs against time, representing area-wise trend. The graphs show that when comparing case 1 with case 2, there is a shift of plan towards the city outskirts, because both PoA 153 and PoA 178 are least congested due to their locations. However, the shift is not that extensive due to slight probability of interaction (limited number of displays and diverted attention) and usefulness of information being displayed (all PoAs are not necessarily useful). Case 3 is not much different than case 2. This is because, the social agents eligible to interact distantly are only 5 % of the total population. Even if they are allowed to exchange information, the probability of it being useful is very low. For Case 4, the results show a more extensive and continuous shift in plans pf the agents. Figure 5 highlights that, overall, the agents tend to move to less congested PoAs by revising their activity plans. These shifts may happen either within one area, or from one area to another.

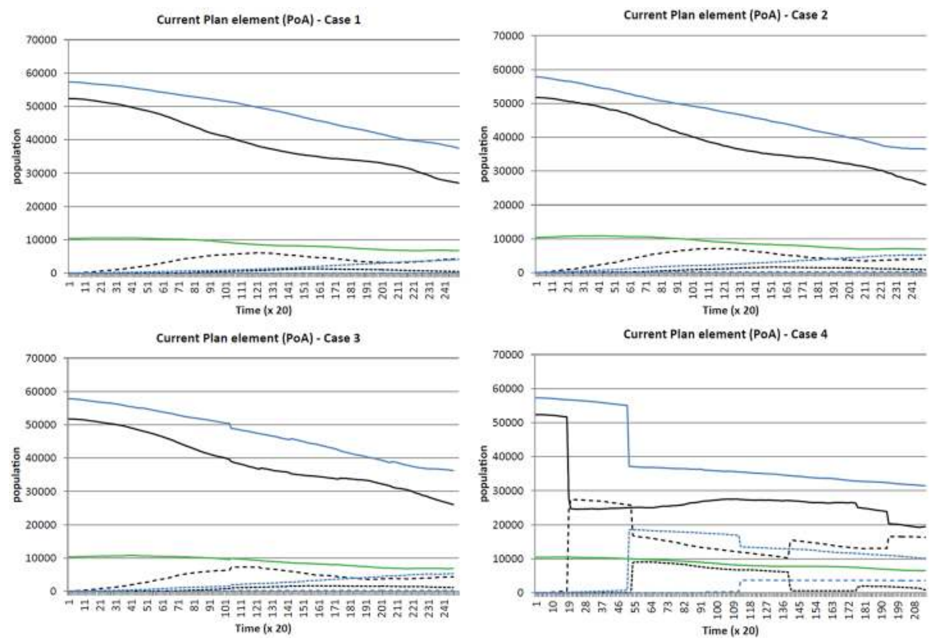

Fig. 5 Area-wise PoAs vs. time. The population plot (*y-axis*) against the simulation time-stamps (*x-axis*), for all four cases. The *graph* represents an abstract view of PoAs in outskirts (*blue*), center (*black*) and urban areas (*green*)

Figure 6 provides a more detailed view of shifts in activity plans of agents. It shows PoA-wise details of all the cases considered in this work and described below:

1. *Case 1* The agents after visiting the PoAss labeled, 6 and 33, start shifting towards the PoAss numbered, 54 (more) and 63 (less), followed by PoA 63 and others.
2. *Case 2* Agents shifted their preferences towards PoAss labeled, 153 and 178 (in the outskirts), which are least congested due to their location. The shift is not that extensive due to combined effect of probabilistic interaction with a display and usefulness of information being displayed (1 out of 12 PoAs was found useful).
3. *Case 3* Case 3 is not much different than case 2. The reason is that the "social" agents eligible to interact distantly were only 5 % of the total population. Even if they exchange information, it has low probability of being useful (1 out of 7–8).
4. *Case 4* Case 4 results in a number of "phase shifts" between different PoAss. These shifts include those within one area (such as center and outskirts) and from one area to the other (such as between center and outskirts). Overall the agents tend to move to less congested PoAs by revising their activity plans. The population status captured at the time-stamp 10,000 (end of simulation) is given in Table 2. These results show that most of the agents are headed towards their final target. In order to compare these results with those of other cases, we use simulation results captured at the time-stamp 5000 (halfway of simulation). This data is provided in Table 2 as well.

Qualitative analysis

Coupling the shift behavior explained above with the models, we compare awareness/attention index of agents with quality of regional density information. Figure 7 shows

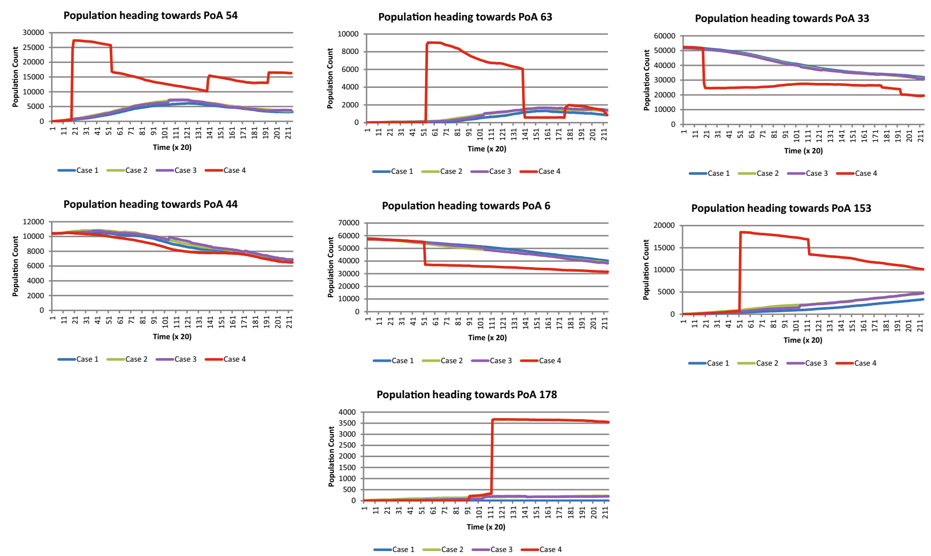

Fig. 6 Individual PoA vs. time. The population plot (*y-axis*) against the simulation time-stamps (*x-axis*), for all four cases, distributed against individual PoA

Table 2 Current PoA in % of population

Simulation time (timestamps)	Case	Point of attraction (labelled as)						
		54	63	33	44	6	178	153
10,000	1	1.8 (D)	0.1 (D)	35 (D)	9 (D)	35 (D)	0.6 (I)	18 (D)
5000	1	5.4 (I)	0.6 (I)	34 (D)	8.4 (D)	47 (D)	0 (–)	5.1 (I)
	2	5.1 (I)	1 (D)	32 (D)	8.6 (D)	46 (D)	0.3 (I)	6.5 (I)
	3	5.4 (I)	1.4 (D)	32 (D)	8.5 (D)	45 (D)	0.2 (I)	6.6 (I)
	4	18 (I)	1 (D)	22 (D)	7.4 (D)	37 (D)	4 (–)	11.5 (D)

Where D is used for decreasing and I for increasing

the attention index and density deviation (y-axis) of the population of agents at all the regions of the city with increase in time (x-axis). The graphs are arranged in a manner that the y-axis starts from 0 on the top and ends at 199 at the bottom, thus representing the regions in increasing order. However, this ordering has nothing to do with city morphology. For example, PoA 33 reside in region 33, which is shown at 34th row on two graphs.

The collective attention is the average attention index (against all PoAs) of all the agents in a region. Figure 7 shows that it increases from Case 2 to Case 4. The concentration of higher index is where the displays are—central and urban regions of the city. The density deviation is the average difference between percepted (situated) density and the real density (of all regions) of all the agents in a region. Figure 7 shows that it decreases from Case 2 to Case 4.

In Case 2, the average attention value (of all agents against the complete set of PoAs) was observed to be 0.037719. It increased a little to 0.044376 in Case 3, due to the localized effect of displays. However, in Case 4, the value of attention index was increased to 0.351935, which indicates a higher degree of attention. The higher attention was

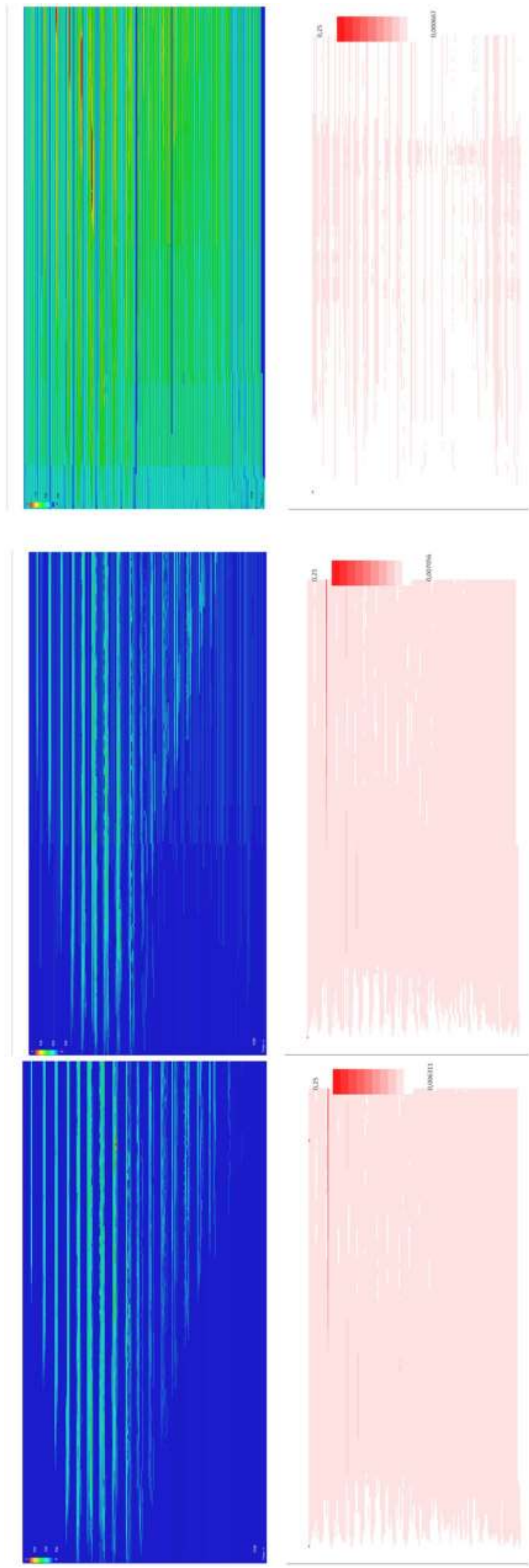

Fig. 7 *Above* Attention index (*y-axis*) of the segments of the city with increase in time (*x-axis*) for case 2 (*left*), 3 (*middle*) and 4 (*right*). *Below* Deviation in density (*y-axis*) of the segments of the city with increase in time (*x-axis*) for case 2 (*left*), 3 (*middle*) and 4 (*right*)

transformed into quality information indicated by less deviation between real and situated (calculated) density. This deviation was 0.031873 in Case 2, which was decreased to 0.031869 in Case 3. It was further acquires a substantial decrement to 0.012959 in Case 4.

Conclusion

The main objective of this paper was to investigate the behavioral change in an urban population based on, information and its dispersion, and activity based mobility. In other words, this work investigated the influence of the information about the regional densities and the extent and quality of the awareness of interesting location on an activity plan of a citizen during a city wide event. To materialize this, the empirically evidenced individual awareness model has been extended by integrating a model of social capital and a model of agent's perception, to construct a multi-agent simulation model of a city scale ecosystem of public and private information units. The simulation of the dynamics of collective awareness in a European city of a population of 1,20,000 agents was performed on a supercomputer comprising of 2048 nodes. The simulation results revealed that socially-inspired information eco-systems have potential of influencing the urban mobility behavior due to the high quality of dispersed information (e.g. city's regional densities) in socially-inspired interaction.

Authors' contributions

KZ, and AF conceived and modeled the system. The simulations are performed by KZ. The simulation results are analyzed by KZ, AD and KS. The paper is written by KZ, KS and AM. All authors read and approved the final manuscript.

Author details

[1] Department of Software Engineering, Bahria University, Islamabad, Pakistan. [2] Institute of Pervasive Computing, Johannes Kepler University, Linz, Austria. [3] Department of Computer Science, CIIT, Abbottabad, Pakistan. [4] Department of Computer Engineering, Bahria University, Islamabad, Pakistan.

Competing interests

The authors declare that they have no competing interests.

Received: 11 November 2015 Accepted: 27 June 2016
Published online: 07 July 2016

References

Benford S, Bullock A, Cook N, Harvey P, Ingram R, Lee O (1993) From rooms to cyberspace: models of interaction in large virtual computer spaces. Interact Comput 5(3):217–237

Bijlsma M (2012) SUNSET—next generation approach to sustainable mobility. Whitepaper, SUNSET Consortium. EU FP7 project no. 270228. http://www.sunset-project.eu

Bourdieu P (2008) 15 the forms of capital. Readings in economic sociology, p 280

Collier N (2010) Repast HPC manual. Technical report, p 44

Connected Urban Development. Urban EcoMap—Working Togetheer to Improve Urban Environments. http://urbanecomap.org. Accessed 14 Jun 2010

Dauber CS, Pan K, Han X, Law KH (2006) Human and social behavior in computational modeling and analysis of egress. Autom Constr 15(4):448–461

de Vries P, Midden C, Bouwhuis D (2003) The effects of errors on system trust, self-confidence, and the allocation of control in route planning. Int J Hum Comput Stud 58(6):719–735

Draghici A, Agiali T, Chilipirea C (2015) Visualization system for human mobility analysis. In: 14th RoEduNet International Conference-Networking in Education and Research (RoEduNet NER). IEEE, New York, p 152–157

Durkheim E (1951) Suicide: a study in sociology (ja spaulding & g. simpson, trans.). Free Press.(Original work published 1897), Glencoe

Ferlander S (2003) The internet, social capital and local community. Unpublished doctoral dissertation, University of Stirling, Stirling

Ferscha A (2014) Attention, please!. IEEE Pervasive Comput 13(1):48–54

Ferscha A, Zia K (2009) LifeBelt: silent directional guidance for crowd evacuation. In: Proceedings of the 13th International Symposium on Wearable Computers (ISWC '09), September 4–7 2009, Linz. IEEE Computer Society Press, New York

Ferscha A, Zia K, Gollan B (2012) Collective attention through public displays. In: IEEE Sixth International Conference on Self-Adaptive and Self-Organizing Systems (SASO). IEEE, New York, p 211–216
Fox WM (1995) Sociotechnical system principles and guidelines: past and present. J Appl Behav Sci 31(1):91–105
Giannotti F, Pedreschi D, Pentland A, Lukowicz P, Kossmann D, Crowley J, Helbing D (2012) A planetary nervous system for social mining and collective awareness. Eur Phys J Spec Top 214(1):49–75
Gilbert GN, Troitzsch KG (2005) Simulation for the social scientist. Open University Press, Maidenhead
Haartsen JC (2000) The bluetooth radio system. IEEE Pers Commun 7(1):28–36
Henein CM, White T (2005) Agent-based modelling of forces in crowds. In: Multi-agent and multi-agent-based simulation, lecture notes in computer science, vol. 3415, p 173–184. Springer, New York
Hsu W-J, Merchant K, Shu H-W, Hsu C-H, Helmy A (2005) Weighted waypoint mobility model and its impact on ad hoc networks. SIGMOBILE Mob Comput Commun Rev 9(1):59–63
Jacobs J (1961) The life and death of great American cities. Vintage, New York
Kilpatrick S, Field J, Falk I (2003) Social capital: an analytical tool for exploring lifelong learning and community development. Br Educ Res J 29(3):417–432
Kim H-W, Chan HC, Gupta S (2007) Value-based adoption of mobile internet: an empirical investigation. Decis Support Syst 43(1):111–126
Kim J, Sridhara V, Bohacek S (2009) Realistic mobility simulation of urban mesh networks. Ad Hoc Netw 7(2):411–430
Kirchner A, Schadschneider A (2002) Simulation of evacuation processes using a bionics-inspired cellular automaton model for pedestrian dynamics. Phys A Stat Mech Appl 312(1):260–276
Kretz T, Schreckenberg M (2005) Moore and more and symmetry. Pedestr Evacuat Dyn 2005:297–308
Li X, Zhang X, Yeh A, Liu X (2010) Parallel cellular automata for large-scale urban simulation using load-balancing techniques. Int J Geogr Inform Sci 24:803–820
Lin N (2002) Social capital: a theory of social structure and action, vol 19. Cambridge University Press, Cambridge
Masaryk TG (1909) Simmels soziologie. Zeitschrift für Sozialwissenschaft 12:600–607
Metaxas G, Markopoulos P (2009) Abstractions of awareness: aware of what? In: Markopoulos P, Mackay W, Ruyter B (eds) Awareness systems. Springer London, London, pp 149–173
Mitleton-Kelly E (2013) Co-evolution of intelligent socio-technical systems: modelling and applications in large scale emergency and transport domains. Springer, Berlin
Mulgan G, Leadbeater C (2013) Systems innovation. Discussion paper, Nesta
Pan XS, Han CS, Dauber K, Law KH (2007) A multi-agent based framework for the simulation of human and social behaviors during emergency evacuations. AI Soc 22:113–132
Panou M, Touliou K, Bekiaris E, Gaitanidou E (2010) Pedestrian and multimodal route guidance adaptation for elderly citizens. In: IST-Africa. IEEE, New York, p 1–7
Perumalla KS, Aaby BG, Yoginath SB, Seal SK (2011) Interactive, graphical processing unitbased evaluation of evacuation scenarios at the state scale. Simulation, p 0037549711425236
Putnam RD (1995) Bowling alone: America's declining social capital. J Democr 6(1):65–78
Salah A, Lepri B, Pianesi F, Pentland A (2011) Human behavior understanding for inducing behavioral change: application perspectives. Human behavior unterstanding. Springer, Berlin, pp 1–15
Sestini F (2012) Brave New World—or collective awareness platforms as an engine for sustainability and ethics. European Commission, DG Information Society and Media, April, Technical report, p 17
Solar R, Suppi R, Luque E (2011) High performance distributed cluster-based individual-oriented fish school simulation. Procedia Comput Sci 4:76–85
Sperling G (1967) Successive approximations to a model for short term memory. Acta Psychol 27:285–292
Stoll C (1996) Silicon snake oil: second thoughts on the information highway. Anchor, Garden City
Straub ET (2009) Understanding technology adoption: theory and future directions for informal learning. Rev Educ Res 79(2):625–649
The Young Foundation (2016) Action for happiness project. http://www.actionforhappiness.org. Accessed Jan 2016
Thumbprint Co-operative (2016) Who owns my neighbourhood project. http://whoownsmyneighbourhood.org.uk. Accessed Jan 2016
Tönnies F (1957) Community and society. The urban sociology reader, pp 13–22
Trist E (1981) The evolution of socio-technical systems. Occas Paper 2:1981
Valderrama A, Jrgensen U (2008) Urban transport systems in bogot and copenhagen: an approach from STS. Built Environ 34(2):200–217
Vogt R, Nikolaidis I, Gburzynski P (2012) A realistic outdoor urban pedestrian mobility model. Simul Model Prac Theory 26:113–134
Vukadinovic V, Dreier F, Mangold S (2011) A simple framework to simulate the mobility and activity of theme park visitors. In: Proceedings of the Winter Simulation Conference, pp 3253–3265
Warschauer M (2004) Technology and social inclusion: rethinking the digital divide. MIT press, Cambridge
Weiser M (1999) The computer for the 21st century. SIGMOBILE Mob Comput Commun Rev 3:3–11
Wellman B, Haythornthwaite CA (2002) The Internet in everyday life. Blackwell, Oxford