Weaving Space into the Web of Trust: An Asymmetric Spatial Trust Model for Social Networks

Mohamed Bishr

Institute for Geoinformatics,
University of Muenster,
Robert-Koch-Str. 26-28,
48149 Muenster, Germany
m.bishr@uni-muenster.de

Abstract. The proliferation of Geo-Information (GI) production in web-based collaboration environments such as mapping mashups built on top of mapping APIs such as GoogleMaps API poses new challenges to GI Science. In this environment, millions of users are not only consumers of GI but they are also producers. A major challenge is how to manage this huge flow of information and identify high value contributions while discarding others. The social nature of the collaborative approaches to GI provides the inspiration for innovative solutions. In this paper, we propose a novel spatial trust model for social networks. This model is part of our research to formalize the spatio-temporal regularities of trust in social networks. The presented model provides a metric for trust as a proxy for GI quality to assess the value of collaborative contributions. We also introduce the underlying network for the model, which is a hybrid network structure for collaborative GI applications based on affiliation networks and one-mood continuous trust networks. Trust calculation in the affiliation network takes into account the geographic distance between the actors and their information contributions –also known as events–, while the one-mood network does not. This leads to an asymmetric model with respect to the representation of space.

Keywords: Trust, space, spatial, quality, proxy, social networks, trust model.

1 Introduction

The notion of trust in computer science has many definitions depending on the application domain. It is a descriptor of security and encryption [KA98], a name for authentication methods or digital signatures [An01], a factor in game theory [MRS03], and a motivation for online interaction and recommender systems [AH98]. In this paper we are concerned with the web of trust and particularly consider the social aspect of trust in web based social networks (WBSN) and define it as a representative of personal values, beliefs and preferences. This type of social trust has been studied in previous work such as [Go05, MSC04, RAD03, ZL04]. As further explained in this paper, the majority of this research has been on the usage of trust as a measure of the quality and relevance of information in social networks of online communities.

In [BK07] we discussed two different examples of collaborative GI environments, Openstreetmap.org and Wayfaring.com. Each has its own unique aspects as a collaborative GI application. Wayfaring.com in particular demonstrates mapping mashups built over mapping data exposed through new Mapping APIs such as Google and Yahoo Mapping APIs. The wealth of information layers added to these mapping data are characterized by locality, as users contribute local knowledge and by breadth of scope with a variety of information such as pictures, restaurant reviews, jogging tracks and much more. Such layers of knowledge are otherwise hard to acquire on such a large scale and they make the underlying datasets ever richer and more valuable. We identified some shortcomings associated with these collaborative GI environments due to the transformation of users from GI content consumers to GI content producers. This transformation certainly raises new challenges with respect to the management of GI and its semantics. Also in [BK07] we presented a scenario where we pointed out the increasing demands for up-to-date geographic information in the context of road navigation for truck drivers. To overcome the above challenges, it is important to understand which users provide valuable contributions and which do not, both in data and its metadata. A major obstacle to this is the lack of quality measures of collaboratively generated GI since traditional quality measures (lineage, accuracy, consistency and completeness) are almost impossible to determine in such application environments.

In this paper, we present a novel approach to use trust in social networks as a proxy of GI quality. The hypothesis of this approach is that trust as a proxy for geospatial information quality has a spatio-temporal dimension that needs to be made explicit for the development of effective trust based GI quality metrics. The spatial dimension acts as a measure of the confidence in the trust rated events. Our goal is a spatio-temporal model of trust in social networks. This spatio-temporal trust model should identify trusted information contributions by users as well as identify and reaffirm trust in those users who contributed and continue to contribute information. In our approach, space and time are orthogonal dimensions and therefore the proposed model separates between them. In this paper, we only focus on the spatial dimension of trust in social networks.

The asymmetric spatial model of trust in social networks introduced in this paper is based on a hybrid social network model consisting of two interlinked networks:

- a two-mood non-dyadic affiliation network represented by a bipartite graph. In the affiliation network, we refer to the information contributions of the actors as events. The links between actors and events in the affiliation network are weighted by the distance between the location of the actors (presumably home base address) and the location of the events.
- A one-mode network of actors as one-mood continuous trust-rating network [Go05].

The proposed model is said to be asymmetric because space is represented only in the affiliation network in terms of geographic distance between actors and events, while the confidence in one-mood network trust ratings remains insensitive to space.

2 Trust In Social Networks

Trust from a sociological point of view is a prerequisite for the existence of a community, as functioning societies rely heavily on trust among their members [Co01, Fu96, Us02]. "The existence of trust is an essential component of all enduring social relationships" [Se97 p. 13]. Online communities much like real life communities rely on trust that is either implicit between the community members or explicit where users rate each others with a numerical measure of trust as studied in [Go05, ZPM05].

The inclusion of a computable notion of trust into social networks requires a simple definition of the term that preserves relevant properties of trust in our social life [Go05]. A simple yet inclusive definition of trust, which we adopt for our work is *"Trust is a bet about the future contingent actions of others"* [Sz99]. There are two components to this definition, belief and commitment [Go05]. The person (trustor) believes that another person (trustee) will act in a certain way. Then, the trustor commits to an action based on that belief. Four properties of trust on WBSN are also identified [Go05], namely:

- Transitivity
- Composability
- Personalization
- Asymmetry

These basic properties of trust are well grounded in our adopted definition of trust and will be considered in the formal model discussed in this paper. For further details on these trust properties and their relation to the adopted definition we refer the reader to [Go05, RAD03, ZL04]. An additional property of trust that we endorse for our work is presented in [Sz99], trust is essentially about people, and behind complex constructs, that we may vest trust in, always lays individuals whom ultimately we endow with trust. In Sztompka's [Sz99] view to trust Lufthansa for a flight to Tokyo means you trust the pilots, cabin crew, and ground crew and so on. It easily follows that if you trust certain information, you trust the person or persons behind this information. This allows for a possible transition from trust between individuals to trust the information provided by those trusted individuals.

Trust in WBSNs is a measure of how information produced by some network users is relatively valuable to others [Go05, ZPM05, ZL04]. Trusted users tend to provide more useful and relevant information compared to less trusted or un-trusted users. With the lack of traditional information-quality attributes (lineage, accuracy, consistency and completeness) in collaborative environments, we propose to use trust as a proxy for geospatial information quality. Quality is a subjective measure here (and always, to some extent); if some trust-rated geospatial information is useful and relevant to a larger group of users, it can then be assumed to have a satisfactory quality in a more objective sense.

3 Spatial Aspects of Trust in Social Networks

The evolution of social networks with respect to the spatial dynamics, directly relating network evolution to constraints defined by the geographic space was studied in [MM05]. In their study of trust [BK95, BK96] provide evidence about the effects of social network structures on trust. Networks of high density compel actors to confirm each other's opinions rather than argue about differences. Therefore, actors in dense networks tend to have more extreme opinions about the trustworthiness of others compared to actors in less dense networks. These opinions can veer towards trust or distrust. The dynamics of the emergence of these opinions are not explained. However, the network dynamics approaches discussed in [NBW06,Wa04,WS98] provide interesting insights on the role network dynamics can play in enhancing our understanding the trusting behavior of actors in social networks.

"Homophily is the principle that a contact between similar people occurs at a higher rate than among dissimilar people. The pervasive fact of homophily means that cultural, behavioral, genetic, or material information that flows through networks will tend to be localized" [MSC01 p.416]. In their study of homophily, [MSC01] asserts that space is a very basic source of homophily. People are more likely to have contact with those others who are geographically closer than with others further away. A justification for this natural tendency is provided in [Zi49] as a matter of effort: it takes more effort (time, attention, etc.) to connect to those who are faraway than those who are closer. Many studies have illustrated this correlation between geography and establishment of connections between people [Ca90,Ga68]. Furthermore, factors that seem trivial such as arrangement of streets do have a direct effect on the formation of relatively weak ties and the potential for strong friendship formation [HW00, Su88].

With the proliferation of communications, the web and its pervasiveness one can expect that these technologies have had an effect on the extent to which geography affects social networks. These new technologies have apparently loosened the effects of geography by lowering the effort involved in creating and maintaining contacts [KC93]. Despite this loosening effect of new technologies [We96a] shows that social networks maintained through technological means still show geographic patterns. Also [Ve83] shows that geographic proximity is still the single best determinant of how often friends socialize together. In [We96b] it also becomes clear that new communication technologies have allowed people greater affordances in making homophiles relations through other dimensions (e.g., those with pet hobbies can form relations over the internet with others anywhere in the world more often than in the past). "these technologies seem to have introduced something of a curvilinear relationship between physical space and network association, with very close proximity no longer being so privileged over intermediate distances but both being considerably more likely than distant relations"[MSC01 p.430]. Also [MSC01] continues to assert that geography seems more important in determining the *"thickness"* of a relationship, which pertains to its multiplexity and frequency of contact.

Although the effects of the spatial dimension on trust particularly in social networks are not fully understood, this "*thickness"* of the relationships described by McPherson [MSC01] is a strong determinant of trust [Se97, Sz99]. Other factors such as the outcome of each encounter between actors (positive/negative experiences), the nature of those encounters and their importance to the parties involved also strongly affect trust [Bu02, Se97, Sz99]. One notices the multidimensional nature of social relations [Wa04], where space is a factor that helps shape the current nature and the future of those relations and consequently the levels of trust inherent in those relations.

Temporal and spatial aspects of trust in organizations are discussed in [Rä04] by grounding his discussions in the Greek notions of chronos(clock time)/kiros(right moments) for time and their spatial counter parts chora(abstract space)/topos(concrete place). He tries to lay the philosophical foundations of how those notions affect trust particularly in time management and virtual organization settings. However, no conclusions are made about a direct effect of geographical space on trust. In the context of studying networks of organizations [NE92] argues that partners in close proximity to each other are almost often preferred partners, which means that network embeddedness (the over all network structures and mutual relations of actors) is ultimately affected by geographical space. In addition, [Bu02] suggests a direct link between geographical space and trust in social networks. He uses geographic distance as an indicator of network density among firms. His assumption is that there is a higher probability that firms located geographically closer together will have ties to common third parties and also that these third parties have more contacts among each others making the social network dense in social ties as a result of geographic space which eventually fosters trust in the social network.

4 An Asymmetric Spatial Trust Model for Social Networks

In our view trust is inferred about people not about inanimate objects [Sz99]. We are adopting here a social definition of trust as we previously discussed. To trust information contributed by the actors is to implicitly trust actors who contributed this information. In that sense there is a certain unity or tie between actors and information they contribute, our proposition is that geographic distance affects the confidence we have in a user's trust rating of a certain information entity. We suggest that this tie can be viewed as a physical affiliation in graph theoretic terms. Initially we propose to view the actors contributing information as a bipartite graph (Fig. 1). We will refer from now on to information contributions where a user is reporting a roadblock for example as "events". In a bipartite graph, there are two subsets of nodes and all lines are between nodes belonging to the subsets. Formally, in a bipartite graph, nodes in a given subset are adjacent to nodes from the other subset, but no node is adjacent to any node in its own subset [WF94]. Our hybrid network consists of both an affiliation network and a one-mood [Wf94] actors network. Before discussing the model, we address two basic assumptions that are derived from our previously discussed study of the prior work on the spatial aspects of social networks and trust:

- **assumption 1:** trust in events increases as the number of users tagging the event increases.
- **assumption 2:** we have higher confidence in trust ratings of actors who are geospatially closer to events. In that sense distance in our model affects the *confidence* in a trust rating of an information entity.

Model Description

In social network terms, the resulting bipartite graph of actors and contributions is a two mood non-dyadic affiliation network. Actors are possibly affiliated to many contributions and contributions are possibly contributed by many actors. Hence, our affiliation network consists of a set of actors and a set of events. We observe two sets of nodes representing the two moods of the network (Fig. 1):

***N*:** is the set of all actors who are contributing information (events) to the network $N = \{n_1, n_2, ..., n_g\}$. Those actors can be viewed in terms of the subset of events to which he contributed.

***M*:** Is the set of all events that are contributed by actors *n,* $M = \{m_1, m_2, ...m_h\}$ similar to the members of the set *N,* events can also be viewed in terms of the subset of actors who contributed to these events.

The affiliation network shown in (Fig. 1) is said to be non-dyadic. In non-dyadic networks the affiliations formed around the events in this network consist of subsets of actors such that event $M_1 = \{n_2, n_5, n_6\}$. Therefore, relations are not anymore between pairs of nodes as opposed to one-mood networks. Of course in such a network actors can also be viewed as subsets of events such that actor $N_2 = \{m_1, m_3, m_5\}$. However, at this stage of the model we are interested only in the events as subsets M_h. From this initial setting, our first measure of the quality of the events can be conveyed with the graph theoretic nodal degree measure.

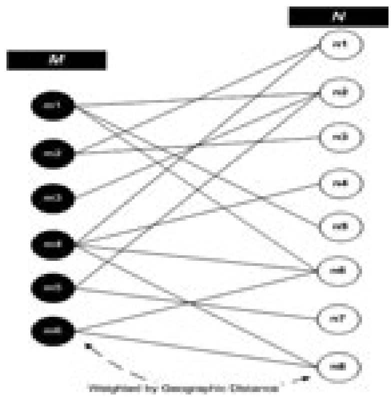


Fig. 1. The affiliation network of actors and the events (information they contributed). The links representing the affiliation is weighted by geographic distance to incorporate distance effects in the model

For a graph with *g* nodes, the degree of a node denoted $d(m_h)$ is simply the number of lines that are incident with it. The nodal degree can range from 0 if no lines are incident with a given node to $g-1$ if a node is adjacent to all other nodes in a graph. In our bipartite graph of actors and events one can measure the nodal degrees of the events, which essentially would represent the number of members in the subset M_h. One should note that in the proposed model the nodal degree will never be 0 and will have a minimum of 1 since each event only exists in response to an initial user contribution. The nodal degree here is a simple albeit a very telling measure of the importance of a particular node/event [WF94]. In our case it tells us how many actors/users have actually bookmarked a certain location as a roadblock for example. Considering such a measure, the higher the nodal degree of the event the more we can reaffirm trust in the information provided since this means that more people are reaffirming it. Given the property of trust we adopted earlier from [Sz99] this is a highly acceptable measure.

However, when calculating the nodal degree in the standard graph theoretic method it is assumed that all the links from actors to events are of equal importance. This is contrary to reality since some users will be inclined to provide more relevant information. As previously discussed, the hypothesis underlying this model is that the spatial dimension is a strong governing factor to this inclination to trust users in providing more accurate information. This view is supported by evidence from our discussion of the spatial aspects of trust in social networks. Hence, we propose a representation of space, particularly distance as a weight to the links when calculating the nodal degrees. Events whose users are closer to the event location (e.g. higher relative proximity) receive a better rating of trust than these events whose users are further away. This spatial nodal degree measure will be denoted $\grave{d}(m_h)$. We assume the location of the actor to dynamically his location when reporting an event (i.e. collected from a mobile device, personal reporting) and the distance from the event location to be the direct geographic distance in a straight line. In the nodal degree calculation every link between an actor and an event is counted as one. For example the nodal degree of the event m_1 is 3 and m_4 is 4 (Fig. 1). For our distance adjusted nodal degree for event nodes, we take a naïve representation of distance by dividing each nodal degree $e = 1$ by the corresponding distance c , thus:

$$`d(m_h) = \sum_{i=1}^{k} \frac{e}{c_i} \qquad \textbf{(1)}$$

In our case e is always 1, thus:

$$`d(m_h) = \sum_{i=1}^{k} \frac{1}{c_i} \qquad \textbf{(2)}$$

The spatial nodal degree makes the trust inference about the events spatially sensitive, hence adding effects of geography to the social space. However, we don't intend to use this measure alone as a measure of trust in information quality provided by the user. Rather the intention of our model is to make the effects of social trust on the model more explicit. Therefore, we proceed to discuss the second element of the model that integrates continuous trust networks into the model [Go05].

As a common analysis method of affiliation networks, the bipartite graph of the affiliation network can be folded into two one-mood networks one which presents the connections between actors based on affiliation with events, and another which represents the connections between events based on affiliation with actors. At this stage we are not trying to define the meaning of both networks. The distinction here is that the one-mood network of actors that will be discussed next is not resulting from the folded bi-partite graphs. Rather it is a continuous trust network of actors where ties represent trust ratings on a scale of 1-10 [Go05]. Our model requires the underlying system to provide facility for these direct user-to-user ratings forming a standard one-mood network of actors (Fig. 2)

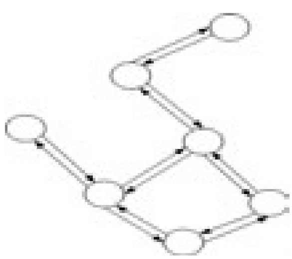


Fig. 2. : The one-mood trust network. This trust network is by definition directed and represents the asymmetry property of trust earlier discussed (rating from A→B ≠ B→A)

The resulting network is presented in (Fig. 3). This form of network is not strictly an affiliation network. In an affiliation network the actors are not connected, but rather connect through affiliation with events. In our model, actors have two types of connections:

- Connection with events (the affiliation network)
- Connections among themselves (one-mood continuous trust network).

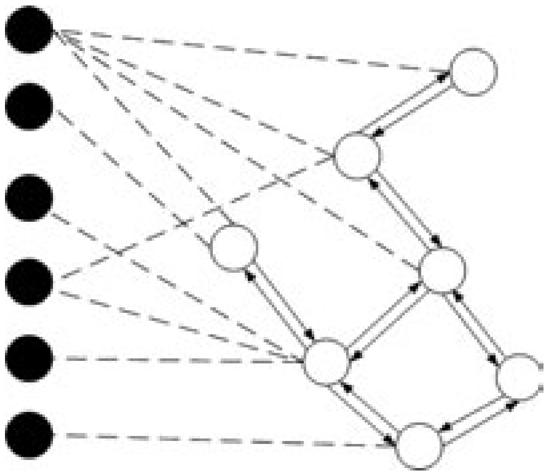
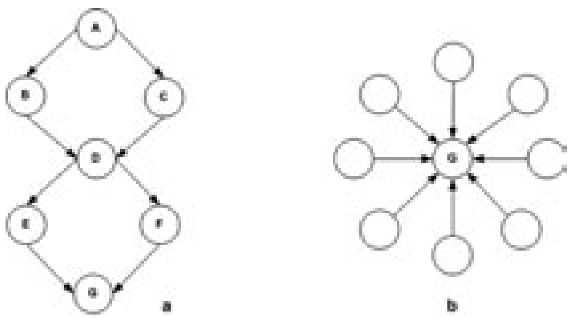


Fig. 3. The depicted network structure represents the fusion of both the one-mood network (white ←→white) and the affiliation network (white→black). The model depends on the interplay between those two networks, as distinct networks within the same structure.

The continuous trust network is used to provide a more explicit account of trust which is bound to a formally well defined notion of trust [Go05, ZL04]. This is best explained by an example. In the network in (Fig.1) Alice (n_2) has contributed to the event m_3 (let us assume it is a roadblock). When calculating the nodal degrees we weight the links by distance. This is assuming that all actors in the set $M_3 = \{n_2, n_5, n_6\}$ contributing to the event m_3 are similar in every respect. This assumption does not hold true when actors are part of a continuous trust network themselves. In that case, trust ratings of the individual actors can be used as weights to reaffirm the ties between the actors and the events through differentiation between actors by their reputation inherited from their trust levels within the social network. Alice in that example is a member of a social network and she has been rated by her peers on the trust scale. We then need to identify what is the over all trust rating of Alice inferred from the social network? This trust rating will then be used as the weight for Alice when making the overall trust rating for an event to which Alice contributed.

The problem of trust inference in the one-mood network is different from [Go05], where the problem of trust is focused on determining how much does A (source) trust G (sink) (Fig. 4(a)) who are not directly connected. In our problem Alice is the sink G (Fig. 4(b)) for which we would like to find a trust rating from the adjacent neighbors and there is no source to infer trust from along the paths. The solution to our inference problem can follow a different methodology albeit with a slightly similar averaging technique as in [Go05].



a b

Fig. 4. In [Go05] (a) the problem is computing trust along the paths from source A to sink G. In our case (b), the problem is computing trust to the sink at one degree of separation

Trust rating for a certain sink node (n_g) will be taken as the average of trust ratings directed inwards from the nodes immediately adjacent to it at one degree of separation. That is to say, the geodesic (social) distance $d(i,g)$ is always equal to 1 between the neighbors and the sink (G). The sink node n_g would have a trust rating of t_{n_g} defined by Equation 3 letting N be the number of adjacent nodes. Equation 3 respects the properties of trust discussed earlier, particularly composability, asymmetry and personalization. However, transitivity is not relevant at this stage, since we compute trust at one degree of separation from the sink.

$$t_{n_g} = \frac{\sum_{n_i \in adj(n_g), i=1}^{\mathrm{N}} t_{n_i n_g}}{\mathrm{N}} \qquad \textbf{(3)}$$

The integration of the spatial nodal degree as a trust measure (Equation 2) and the trust measure from the one-mood actors network (Equation 3) as a weight for the actors will then provide our global trust level in a certain event. For an event m_h the final trust rating t_{m_h} is defined by Equation 4.

$$t_{m_h} = \sum_{i=1, g=1}^{k} \frac{t_{n_g}}{c_i} \qquad \textbf{(4)}$$

Equation 4 establishes a trust metric for information contributed by actors. This metric has an explicit account of geographic distance inherited through the affiliation network as well as an explicit account of trust inherited through the one-mood network. An important decision we made is what we refer to as the asymmetry of the model. This asymmetry of the model is revisited in the last section.

5 Conclusions and Future Work

In this paper we proposed an approach to formalize how distance affects the confidence we might have in trust of certain information entity reported by moving social network agents. A major challenge we have is in establishing a distance threshold after which the confidence effect would have a stable maximum value. Generally, defining such a threshold should involve real world analysis of actual data to fine tune the current model. Also the representation of distance as introduced in the model should be normalized. However the distance measure as represented is remains relevant, as suggested by some recent research [MWB07].

An important point is our choice not to make the continuous one-mood trust network spatially sensitive (asymmetry of the model). This is contrary to evidence suggesting that the continuous one-mood trust network is sensitive to the spatial dimension [Bu02, NE92]. It is clear then that our model will have to be symmetric. That is to account for space in the one-mood continuous trust network when doing trust calculations to the sink. However, accounting for space in both networks at this stage will make the results of any analysis very hard to interpret since it will be difficult to disentangle the effects of space in the one-mood network from those of space in the affiliation network. Hence, the best way forward was to study both as flip sides of a coin before integrating the spatial dimension into both networks in a unified model if so proves more accurate.

Currently our model depends on structural social network analysis methods such as the nodal degree and averaging of trust values of adjacent nodes. However, a modern and emerging view in the science of networks is network dynamics [BC03,Wa04]. In this view, analysis for networks including social networks without a corresponding theory of dynamics is essentially un-interpretable [Wa04]. Actors are not static nodes in a network structure that is the an embodiment of their relations. Actors are human beings moving in space and time, doing activates and responding to a changing environment. In studying trust, our model assumes a network of a given structure as a still image and tries to propagate trust across this network. From a network dynamics perspective we are interested in how trust evolves and develops over the network in both space and time and how trust propagation ultimately affects the structure of the networks. In other words, our presented spatial trust model will have to be accompanied by a corresponding theory of dynamics of trust on social networks.

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