Towards Socially Aware Mobile Phones

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Abstract. Mobile phones currently represent the most pervasive technology for enabling social networking. They collect a wide range of socially meaningful data, such as address book contacts, pictures, call logs and exchanged messages. This data, however, is highly underutilized as it is managed by separate applications which are typically unaware of the user's social setting. This "unawareness" makes the user a slave of his device instead of helping him achieve his goals or manage his everyday activities. Enhancing next generation mobile phone with socially-aware features will provide significant benefits. In this paper, we present real data collected from a user study about mobile phone usage, with the aim of providing evidence for the need of socially-aware phone applications. As a relevant example of socially-aware capability, we analyze the case of interruption management, i.e., how and why users respond to an incoming call or message by interrupting their current activity. To automate interruption management on mobile phones, we suggest the adoption of a policy-based approach to express socially-aware policies based on Semantic Web technologies.

1 Introduction

Social bindings characterize each individual's life. From friendship to professional activities, to family bindings, every person is connected to a number of other individuals within the framework of a so-called social network. Technology advances in portable devices, such as mobile phones, offer a unique chance to support and improve social networking activities. In particular, mobile phones represent the most pervasive social networking tools that users currently exploit to build, maintain and manage the social networks they participate in [5]. Within their social networks users tend to coordinate mobile phone use according to group needs, expectations and social context [1].

Despite their role in social networking, mobile phones are currently equipped with software applications that are largely unaware of the users' social setting. Indeed, the plethora of new features available on mobile phones tends to make the user a slave of his device instead of helping him to achieve his goals and manage his everyday activities. For example, we witness how often people are interrupted by incoming phone calls and messages, which not only disturb the user but also his surroundings. Many of these interruptions could be avoided or adequately managed, only if the phone could adapt its behavior to the specific circumstances when the call is received. On the contrary, to utilize mobile phone applications the user has to adapt himself to the device and application logics-which happens every time we are forced to learn how to use another application running on our phone. Meanwhile, the burden of managing social norms and patterns implied by mobile phone usage is left to the user. For instance, when one is in a meeting, he must remember to switch the phone to silent and decide whether to pick up any incoming call. If the caller could be informed that the called person is in a meeting, she might decide to call at a better time, thus avoiding useless interruptions and possible socially embarrassing situations.

The mobile phone has great potential as enabling means of social networking. Users' mobile phones carry in fact a considerable amount of socially meaningful data, such as contacts in the address book, pictures, call logs recording communication activity between users, and exchanged text messages or emails. This data, however, is highly underutilized as they are managed by separate applications and accessed by phone owners only when a specific information is needed. The result is a paradoxical situation, where mobile phones are equipped with inadequate software applications that are unable to exploit the huge amount of socially-related data they collect from the user.

We claim that next generation mobile phone applications should be enhanced with socially-aware features. To validate our arguments, we present real data collected from a user study we have conducted about mobile phone usage. As a relevant example of socially aware capability, we analyze the case of interruption management, i.e. how and why users decide to respond to an incoming call or message by interrupting their current activity. Users' activity of managing interruptions has been shown to have strong social underpinnings [5] . Novel mobile phone applications should therefore support users in regulating interruptions by (partially) automating features that, at present, are totally managed by hand.

Semantic technologies and policies seem to represent a promising solution to address this issue. Semantic languages permit to build an interconnected graph of socially meaningful data modeled according to an unambiguous semantics. This allows the exchange of social data without loss of meaning between both different applications and different users. In particular, in this paper we suggest the adoption of a policy-based approach to express socially-aware policies regulating mobile phone interruptions. At a high level, policies can be defined as directives ruling the behavior of (entities within) a system. Policies can therefore be used to establish under which conditions the user can be interrupted by a call or a message.

This paper will present some results from our study to provide useful insights about users' social needs and preferences with respect to mobile phone interruptions. The paper is organized as follows. Section 2 provides an overview of motivations and goals for our study, which is presented in Section 3. Section 4 presents our approach to a semantic policy-based framework to handle interruptions on mobile phones. Ongoing work and future research directions are outlined in Section 5, before conclusions in Section 6.

2 Analyzing Interruption Management to Understand Users' Social Needs

We have conducted a user study to determine and analyze which elements play a relevant role in users' decisions about mobile phone interruption management. People are often interrupted by incoming calls and messages. Interruptions have both a personal and a social impact [4]. Let us consider, for example, the case of a user receiving a call while talking with a colleague. Answering the call requires the user's personal attention, and has an influence on his social activity since the conversation is interrupted. Because of the social impact caused by mobile phone interruptions, we suggest that their analysis provides valuable information about users' social needs and expectations with respect to mobile phone usage. In particular, by observing how interruptions are currently handled by users, we might derive useful design insights to (at least partially) automate interruption management.

Understanding when the user can be interrupted is, however, a challenging issue. Users themselves often find it difficult to think of all situations in which they will be interruptible a priori. There are different ways for the user to limit and/or avoid such interruptions. Examples of possible strategies include:

- filtering calls from certain callers, or at certain times
- being provided with information about the call (e.g. urgency, topic) and the caller to decide whether to respond to it
- provide information about the user situation to the caller, and/or a better time to call, and let him decide whether to call
- adapt the phone settings to the social protocol of the situation/location, e.g. switching the phone to silent mode

Currently, all the above mentioned strategies are manually performed by the user, who decides when to respond to incoming calls; might be able to figure out when a call is urgent or expected; might provide information, e.g. via SMS, about his current status; and is in charge of switching the ringing tone to silent when required by the situation, e.g. at the movie theatre.

These strategies for interruption management can be grouped under two main categories of activities, namely:

- call filtering, e.g. based on caller identity, situation and time
- status information sharing, such as current location, activity, etc.

Our study is focused on the two above outlined activities. In particular, for each of them, we try to identify relevant factors and actions. With the term factors we denote decisional elements that help the user in making choices about call filtering and status sharing. By actions we mean those actions that are currently performed by users to filter calls and/or messages, and to share or

disclose information their status.
We provide a list of factors and actions, respectively, that our study has tried to define.

1. Factors governing the user's decision about whether to pick up calls/respond to messages. Examples might include the place where the user is located or the activity he is engaged in.
2. Factors governing the user's decision about whether to share his status information/location with some contacts in his address book, or possibly the caller. Examples might include the identity of the contact or the particular situation (e.g. work, at home).
3. Factors that are common to many users in their decision making process about call filtering and status sharing. Identifying such popular factors might promote sharing and reuse of preferences/settings between several users.
4. Factors that prevent users from trusting automation on the mobile phone, including social factors. For example, if call filtering was (partially) automated, users might feel a lack of control over their phone.
5. Privacy-related factors that restrain users' behavior in sharing or disclosing status/location information, as well as phone settings, e.g. ringing modality.

Similarly, we outline a set of actions we have tried to derive from our study.

1. Actions that users already take to filter calls or to share status information (e.g. send a text message to say that one is in meeting, therefore he cannot answer).
2. Actions that could be successfully automated, and actions that could hardly be associated to any automatic behavior.
3. Actions that are more likely to be sensitive to failure, thus determining the user's overall tolerance to system failure. For example, sharing a status information might be more sensitive than not filtering a call, which the user can filter himself.

Based on this schema, in the next section we provide insights about the results of our study.

3 Study Results And Evaluation

3.1 Methodology

The study was conducted in two phases. In phase 1 we conducted 14 face-to-face interviews. The results from phase 1 inspired us to do a larger study using which we could substantiate our findings. In the larger study, conducted in phase 2, there were about 50 participants split across Italy and USA. The key idea behind splitting participants across 2 countries was to analyze (and account for) culture specific social behaviors and norms.
In phase 1, we conducted 1 hour interviews with participants from 3 different organizations. During the interview we asked several questions related to the

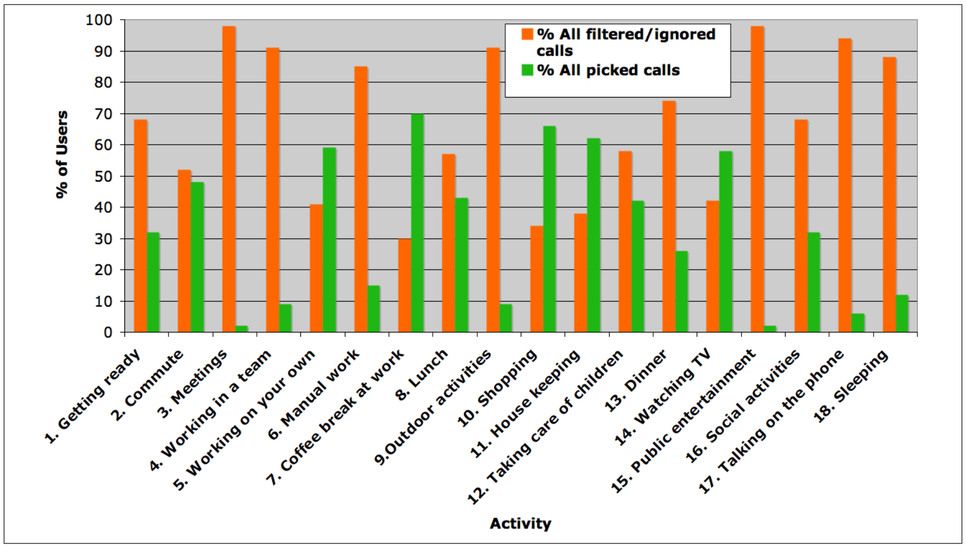

Fig. 1. Activity Based Response to Incoming Calls

subject's daily routine. The questions were targeted to determine the subject's phone usage and interruptibility patterns, and also to determine willingness to share information (like presence, status, settings etc.). We also analyzed some objective data by looking at the user's call logs. We will not discuss the results of the phase 1 study in greater detail; however, we would like to point out that it was a great source of input in designing the questionnaire for phase 2.
In phase 2, we designed an online questionnaire. There were 26 participants from USA and 24 from Italy. The study included 24 males and 26 females in the age range of 20 to 61, with mean 35. We did not have any participants with a software or computer science related background, to avoid any bias due to personal expertise while answering questions, which we experienced in phase 1 of the study.
The important findings from the survey are discussed in the next section.

3.2 Study Results

Activity based call filtering: Despite users' reluctance or possible inability to think in advance of which factors influence their decision to pick up a call, the analysis of everyday activities in section 1 provides evidence to support the idea of activity-based filtering criteria. As seen in Figure 1, most users tend to ignore or filter calls during activities, such as: meetings, while working in a team, during outdoor activities, while sleeping etc. Most of the calls are ignored or filtered by switching the phone to silent mode and by manually screening calls. In many cases, the current activity and the relationship to the caller both contributed to decision making.

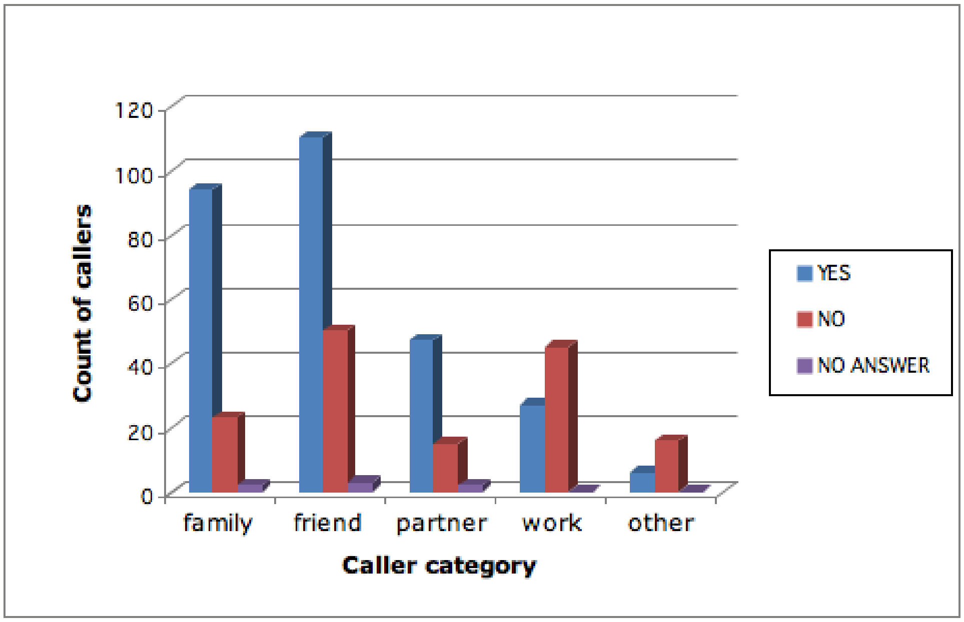

Fig. 2. Willingness to Share Status with Caller

Call filtering: In our study, we asked users if they would be willing to filter incoming calls from some people based on the current activity or event. 67% of the participants did not like the idea of filtering calls automatically, instead they preferred to decide when the call arrived. Willingness to filter calls was equally distributed across people from Italy and USA.
Of the participants who said "no" to call filtering, 82% did not want filtering because they thought it was too difficult to decide in advance what calls to filter. 21% were not willing to filter because it could lead to a lack of control. Some said "no" because they felt it could be too time-consuming and difficult to set such options or because they did not trust the phone to filter out calls correctly.

Sharing the reason for not picking up calls: Many participants (60%) indicated that there had been occasions when they did not pick up a call because of reasons such as poor network coverage, low battery life or cost (ordered by importance). Cost, however, was not a important factor. 84% of the overall participants were willing to share with some or all callers the reason for not picking up the call when the reason was one of the above.

Sharing status with address book contacts: Sharing the user's status using messages (like busy, free, at work, in meeting etc.) with incoming callers or address book contacts can help avoid interruptions.

In our study, 78% of the participants indicated that they would be willing to share status messages with contacts in their address book. 8% were willing to share with all contacts, 62% indicated that they would share with some contacts only and 8% were willing to share based on the situation rather than just the caller. It is interesting to notice that all participants who already share status by using instant messenger applications (IM) were also willing to share status messages with some or all contacts in their address book.
We also collected objective information by analyzing the users' recent (last 5) received and missed calls. For each received and missed call, we asked questions about relationship to caller, communication frequency and willingness to share activity status with the caller. We observed that most of the callers fell under well defined categories such as family, work etc. Figure 2 shows willingness to share status based on category. We can see that willingness to share status is quite high for categories such as family, friend and partner.
Willingness of users to use someone else's status message is an important factor in determining the popularity of status sharing. Overall 84% of the participants said they would use status information before calling another person, for example to avoid disturbing him. Of this, 40% were willing to use this information only for people who frequently updated their status; 18% said they would use this information, but still send a text message to cross-check and 26% said they would use this information anyway.

Sharing location with address book contacts: Sharing location information (also called presence) could provide some context about the user, which could help avoid interruptions.
54% of the participants were willing to share location with some or all contacts at all times or based on the situation. Only 29% of Males were willing to share location, in contrast 77% of the Females were willing to share location. Willingness to share location was equally distributed across people from Italy and USA. Participants with over 200 contacts (20%) were the least willing to share location– 82% said no to location sharing. Participants who share status on IM were the least averse to sharing location– only 9% said no to location sharing.

Traveling scenario: While traveling, people are often concerned about additional costs and timezone differences, their phone usage can often change due to this.
Approximately 65% of the participants said they are more selective with picking up calls, either because of cost (main reason) or because of other reasons (e.g. timezone, don't like getting disturbed etc.). Most people who were more selective, picked up calls based on relationship to caller or based on mental priorities. Calls from unknown numbers were often not picked.
If the phone could inform contacts about travel status (e.g. with messages like "in Italy", "not in town", "reachable after July 6th"), 74% said they would use

this feature with some or all contacts or based on situation.

Phone behavior in public situations: People are often embarrassed in a public place (e.g. library, movie theatre etc.) by having their phone ring because they forgot to put it on silent. This data was generally confirmed by our study. In a public place, the phone could be programmed to turn silent automatically e.g. when in a library, if 40 other phones are on silent, your phone could automatically turn silent. 68% of the participants were willing to use this feature. Of the overall participants, 42% said they would like the phone to prompt first before going silent.
When asked if they would be willing to share their ringer settings with others around (assuming no identifying information is revealed), only 36% said yes. Most participants were not willing to share this information with people around.

Calendar based automation: The phone could use the user's calendar (from PC or phone) to automatically turn silent, when in a meeting. 73% of the users who use a calendar, were willing to use this feature. In some cases people wanted to explicitly select the events for which the phone should turn silent, while some others wanted the phone to prompt them before going silent. 70% of the participants who said no, did not want to use this feature because their calendar was not up-to-date.

Tolerance to failure: The survey also collected information on tolerance to failure while automating the phone's behavior or for information sharing.
Both in the case of sharing location and filtering calls, on average 50% of the participants willing to use these automated features said they would use it only if it worked always. Of the rest, participants seemed to be more tolerant to failure for location sharing: for example, 13% would use it even in case of wrong behavior, but expect others to not rely on this information. Between 30% and 35% of the people said that they would use the location sharing or call filtering feature only if it was free of charge.
Of the people who were willing to use the auto silent feature in public situations, 38% said they would not use this feature unless it worked always and 22% said they would use this feature but not rely on it.

3.3 Evaluation of Results

As far as call filtering is concerned, we observed a strong need to filter calls based on activity, yet we see that most users do not like the option of call filtering. We believe that users would be more willing to use call filtering if the phone made it easy to do so. For instance, the phone could recommend settings based on observed phone usage patterns (that varied by activity and/or relationship to caller). Also, we observed that the same factors, i.e. activities and relationship to the caller, tend to be recurring in users' call filtering decisions. If there

were predefined templates available for popular activities (such as sleeping, in meeting etc.), or for popular relationships (like spouse, close friends etc.,) then people would be more willing to filter calls.
We also noticed that in some situations most users generally adopt similar behaviors about call filtering, such as meetings and sleeping time, while in others their decisions depend on several factors, such as expectations and current mental priority order. Another interesting scenario is represented by traveling, when most people tend to adopt regular strategies to pick up calls.
Regarding status sharing, users generally feel confident about sharing some information with selected contacts. This is supported by both answers to direct questions and call log analysis. For some categories, location seems to be a critical piece of information, probably due to privacy concerns that are generally dependent on social settings and habits. Quite surprisingly, users did not like the idea of sharing their ringer settings, which we considered a not particularly sensitive information. One explanation might be that they don't like to share any kind of information with people they don't know.
Finally, the tolerance to failure is not very high as users expect no mistakes or at least 99% accuracy. It must be said, however, that it might be very difficult for users to assess their tolerance to failure for applications they have never seen nor used.

4 Semantic Policies: a Viable Approach Towards Socially-Aware Mobile Phone Applications

The results of our study show that users currently manage interruptions on their mobile phone both by filtering calls/messages and sharing status information, e.g. via text messages. In particular, the study helped us to outline a number of factors that play a role in the user's decision about answering to calls and showing status information to other people.
Regardless of the specific factors and actions identified in the study, it is worth underlying that users actually discriminate situations (in terms of caller, time, activity, etc.) when they have to make decisions about calls and status information. In other words, users have *strategies* in mind, albeit not always explicit, which they put in action to manage specific situations. As stated above, while some strategies are generally constant with respect to a certain situation (e.g. meetings), others are more difficult to predict since they tend to dynamically change. Therefore, only the former represent a possible choice for supporting automated features.
In particular, in order to build an automated interruption management system, we need to be able to express and enforce user defined "rules of conduct" about call filtering and status sharing. For instance, we might wish to explicitly specify that, during meetings, only urgent calls from family members are allowed. It is interesting to note that both cases, call filtering and status sharing, lend themselves to be modeled as involving *access control* decisions. In the latter case, the accessed resource is status information, while in the former it is the "user's

attention" itself, which we can think of as a particular type of resource owned by the user.
We claim that such user defined strategies can be expressed as access control policies. Policies represent an emerging research direction in the area of access control and security in general. At a high level, policies are defined as directives regulating the behavior of (entities within) a system. Policies have been extensively studied over the last decade and applied to several application fields, from network management, to multi-agent systems regulation, to security [6]. In particular, access control policies define which subject is allowed to access which resources under which circumstances.
Access control policies provide a powerful and expressive model to represent and enforce user preferences and constraints with respect to interruptions. Previous research on policies provides a well-established foundational model for representing directives about how entities operating in a system are allowed/not allowed to access resources, as well as reference architectural models for evaluating and enforcing policies [6]. Existing work also includes tools for policy specification, management and enforcement that have already been utilized in different applications domain [2]. In particular, relevant research efforts have been spent in recent years to integrate semantic technologies within policy definition, thus enabling automated reasoning over expressive policy definitions [3, 9]. We believe that the adoption of semantically rich policies provides a suitable solution to the issue of representing and enforcing user defined strategies for interruption management.

4.1 Socially Aware Policies

The adoption of a policy approach to control interruptions on mobile phones requires the definition of a policy model that can precisely enough identify the basic types of policies required to control access to the user's attention (call filtering) and to information about his status (status sharing), can specify how to express and represent policies in a semantically expressive form, and how to enforce them. In particular, based on the analysis of the results from our study, we consider the following to be requirements that should be considered in the design of a socially aware policy model to regulate interruptions:

- Support for *intensional* rather than extensional definitions of policies. For example, a user would like to define a policy applying to all his "friends" or to "all people depicted in this picture", rather than explicitly naming each person to whom the policy applies.
- Support for *social-aware* modeling of access conditions that reflect the actual relationships between each user and the social environment in which he operates. Social relationships and activities play a crucial role in the user's mental model of sharing and controlling access to his resources, as shown by previous literature in the field [7, 5], and by the results of our study as well.

We suggest that semantic technologies are well suited to model socially aware policies. In particular, we adopt the Semantic Web language RDF to model access control policies. Semantic languages support the intensional definition of policies by allowing the expressive representation, at a high level of abstraction, of the conditions under which a resource can be accessed. Semantic languages also represent a promising solution to the issue of properly representing user's social environment, as efforts like the "Friend-of-a-Friend" (FoaF) initiative demonstrate (http://xmlns.com/foaf/0.1/). In addition, thanks to the ability of performing automated reasoning over social information, semantic techniques might increase the expressivity of user defined socially-aware policies. For instance, a policy applying to a "call" would also apply to a "video call" if we define the latter as an RDF subclass of the former.

Furthermore, a crucial issue in current mobile phone applications lies in the extreme fragmentation of social data. Disseminated within different applications, social data cannot be connected due to the boundaries of the applications that collect and manage them. RDF graphs not only provide a uniform and semantically defined representation for social data, but they also offer the great potential of interconnecting them via semantic links, thus creating a global graph of social information about the user's world. Let us note that interconnection might be needed at the application level, i.e. between different applications running on the device(s) of the same user, and at the social level, i.e. between applications running on behalf of different users or organizations. For example, information about a contact in the user's personal address book could be connected to information extracted from a corporate address book, or a social networking application such as Facebook (http://www.facebook.com).

Finally, we make the note that social data are constantly changing according to user's situation, activities and social relations. Thanks to their extensibility features, semantic techniques are well suited to accommodate (possibly unforeseen) modifications/additions to existing social data, thus allowing for the greater flexibility in policy specification.

4.2 An Example of Socially-Aware Policy

In this section we provide a brief insight on the socially-aware policy model we have developed. A detailed description of the model is out of the scope of this paper. We illustrate an example to show how semantic technologies can be used to model socially aware policies.

In our model, a policy defines all the characterizing information that is considered relevant for access control. This includes information about the entities that might operate on the resource, about the resource itself or other properties, e.g., conditions of the surrounding environment, such as time.

To represent policies we adopt RDF graphs: each policy context is represented as a set of RDF statements about the characterizing elements of a policy, or as SPARQL triple patterns (in the case when there are "unknowns" that have to be matched at policy enforcement time). The use of property paths allows us to represent relationships between the resource, requestor and policy context

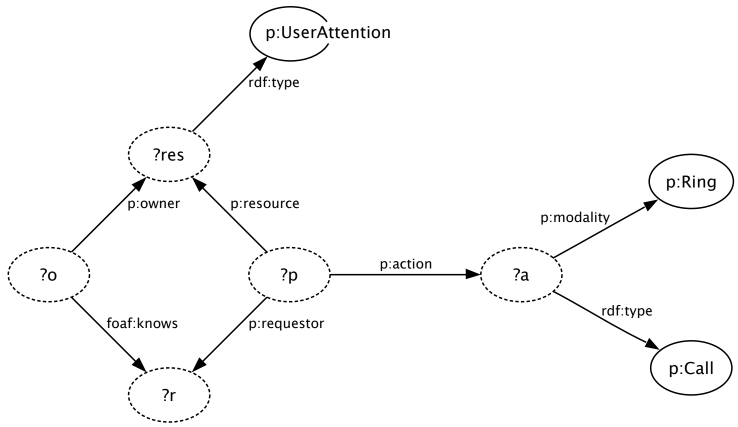

Fig. 3. Query conditions represented graphically as a graph

conditions.
Let us consider for example the following policy: "My phone will ring when people I know call me":

?p `p:requestor` ?r
?p `p:resource` ?res
?res `rdf:type p:UserAttention`
?p `p:action` ?a
?a `rdf:type p:Call`
?a `p:modality p:Ring`
?o `p:owner` ?res
?o `foaf:knows` ?r

This set of (conjunctive) conditions can be thought of as a "graph template", as illustrated in Figure 3.
Figure 4 illustrates a possible (partial) graph that could be matched by the above conditions – note that the nodes inside the dashed oval are data typically stored in the user's social network profile or (with the advent of socially-aware software) possibly in the user's address book.
Let us note that our model does not impose any limitation to the kind of attributes and values that can be defined for policy specification. In fact, the possibility to define customized and application-specific policy constraints allows for great flexibility in policy definition. In our example policies, we used the common attributes to all policy definitions, such as "requestor" or "resource", while others are policy-specific, such as "knows".

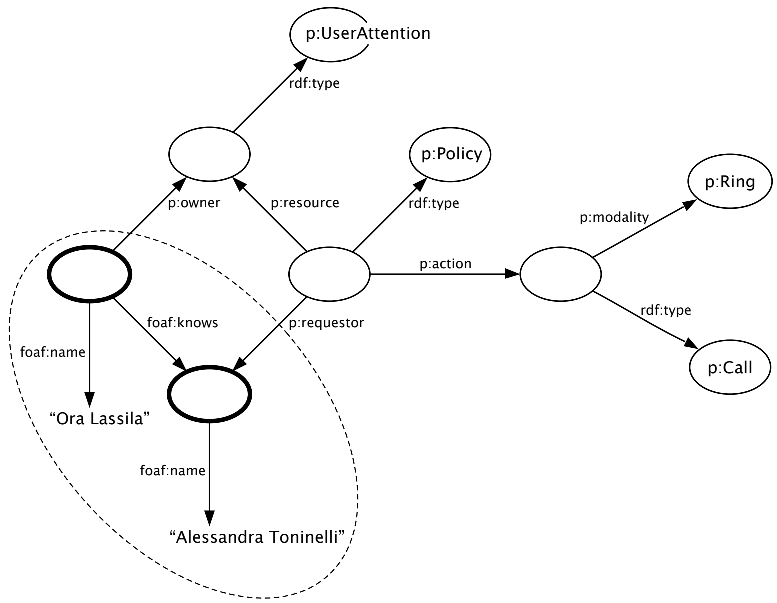

Fig. 4. Possible (partial) graph representing the results of the query

5 Ongoing Work

Based on the policy model presented in Section 4 and on previous work [8], we are working on the design and development of a socially aware policy framework for interruption management on mobile phones.
The framework should provide support for the specification, retrieval and enforcement of semantic policies. In particular, when creating a new policy, a key issue is not only "how" to specify policies, for example via user-friendly graphical interfaces, but also "when" and "where" the user is allowed to specify a policy. As revealed by our study, users often find it difficult to make a priori decisions about how to respond to calls and to share status. Hence, we can expect them to define and/or manage access control policies not as a separate process, but within a certain application context, in which those policies make sense, e.g. when they actually receive a call or need to share status information.
In order to integrate policy specification directly into applications, we are focusing on a customizable policy interface that is designed not only to execute also as a stand-alone application, but also to be activated from the applications installed on mobile devices, such as the calendar or the address book. Similarly to policy definition, policy retrieval mechanisms should be integrated with user applications. It is worth noting that such integration feature strongly relies on the graph-based nature of the RDF-based policy model. A graph-based policy definition can be built and browsed in multiple directions from different starting

nodes, thus allowing multiple definitions and interpretations of the same policy from different perspectives.
In addition, we are further analyzing the results provided by our study, particularly to identify possible correlations between various factors and actions that might provide us with useful insights for the design of our policy framework.

6 Conclusions

Despite being the most pervasive social networking tools, mobile phones are currently equipped with software applications that are largely unaware of the user's social setting. In this paper, we highlight the need for socially-aware mobile phones and the mechanisms needed to enable such social features.
Understanding the user and his needs are fundamental to building a socially-aware phone. Therefore, we conducted a cross-cultural user study with a specific focus on interruption management i.e., how can we better manage interruptions to mobile phone users and their surroundings. The study provided useful insights into scenarios and phone features where automation could help. It has also remarked the importance of keeping automated features easy to use.
We propose to adopt a semantic policy-based approach to express socially-aware policies that can regulate interruptions on mobile phones. The use of a semantic model enables us to utilize the user's fragmented social data and allows support for intensional policy descriptions. The design and implementation of the policy model (and framework), presented in this paper, are still under development.

References

1. W. Campbell and T. Russo. The social construction of mobile telephony. *Communications Monographs*, pages 317–334, 2003.
2. N. Damianou, N. Dulay, E. Lupu, and M. Sloman. The Ponder policy specification language. In *POLICY 2001*.
3. L. Kagal, T. W. Finin, and A. Joshi. A policy language for a pervasive computing environment. In *POLICY 2003*.
4. A. Kahlil. *Context-Aware Telephony and Its Users: Methods to Improve the Accuracy of Mobile Interruptions*. PhD thesis, Indiana University, 2006.
5. J. E. Katz and M. Aakhus. *Perpetual Contact: Mobile Communication, Private Talk, Public Performance*. Cambridge University Press, New York, NY, 2002.
6. M. Sloman. Policy driven management for distributed systems. *Journal of Network Systems Management*, 2(4), 1994.
7. D. S. Tara Whalen and E. F. Churchill. User experiences with sharing and access control. In *CHI '06 extended abstracts on Human factors in computing systems*. ACM Press, 2006.
8. A. Toninelli, et al. A semantic context-aware access control framework for secure collaborations in pervasive computing environments. In *ISWC*, volume 4273 of *LNCS*, pages 473–486. Springer, 2006.
9. A. Uszok, et al. Kaos policy and domain services: Toward a description-logic approach to policy representation, deconfliction, and enforcement. In *POLICY 2003*.