Journal of Universal Computer Science, vol. 16, no. 15 (2010), 2099-2110
submitted: 31/1/10, accepted: 28/7/10, appeared: 1/8/10 © *J.UCS*

Integrating Social Networks for Context Fusion in Mobile Service Platforms

Jason J. Jung
(Knowledge Engineering Laboratory
Department of Computer Engineering
Yeungnam University
Gyeongsan, Korea 712-749
j2jung@{intelligent.pe.kr, gmail.com})

Abstract: It is important for mobile service providers to be aware of user contexts and to provide contextually relevant mobile services to users. Thereby, in this paper, we propose a novel mechanism for integrating online social networks, which are regarded as an important channel for exchanging and propagating contexts. To efficiently discover personal contexts of certain users, the contexts of their neighbors can be fused to provide mobile recommendation services to mobile subscribers. However, since the social network of each user is distributed across several systems, it has been difficult to integrate contexts from distributed social networks. Thereby, we mobilize all possible on- and off-line social networks to build an ego-centric social network. We implemented the proposed system by collecting the social network dataset from online sources (e.g., Facebook, Twitter, CyWorld, and co-authoring patterns in major Korean journals) and offline (e.g., co-participation patterns in a number of Korean domestic conferences). After the system was implemented, we provided mobile services to conference participants by sending text messages about time schedules of relevant presentations.
Key Words: Mobile recommendation service; Social network analysis; Social network portability; Context fusion.
Category: H.1.1, H.3.5, I.2.11

1 Introduction

In order to efficiently provide relevant services to mobile users, it is crucial for mobile service providers to collect as much information as possible about their current situations and to find their “contexts” (e.g., information that users are looking for). More importantly, in order to make better decisions, the context fusion process used to integrate the collected context information should be efficient.

One of the latest approaches for such context-awareness work is to employ social contexts (e.g., users who are socially related) by building a social network among mobile users. Thereby, several studies have been done to elicit social networks from a large number of datasets obtained from telecommunication companies. In particular, so-called “reality mining” [Eagle and Pentland 2006] has introduced possible scenarios using data mining and visualization technologies. A number of types of usage patterns collected from mobile environments have been analyzed to figure out the social relationships between two arbitrary users. Particularly, in our previous work [Jung et al. 2009;Jung 2009a], we have proposed an interactive approach to discover social networks between users.

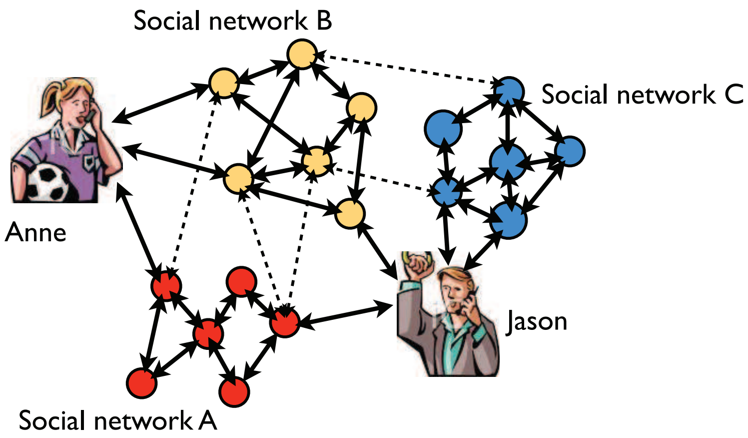

Figure 1: Isolation of social networks

However, there are two main drawbacks on exploiting data mining tools to discover the social networks and to provide mobile users with only restricted services.

Privacy issues The first problem is the difficulty of protecting user privacy. Even when users allowed the company to use their data, we could not establish whether the social networks discovered by the data mining tools were correct or not.

Isolation of social networks The second problem, which is even more serious, is that the discovered social network is isolated (or fragmented). In practice, telecommunication companies have never tried to share their subscriber data with others. Thus, the real dataset we obtained from a given company can reflect only a subset of the social networks we are seeking. As shown in Fig. 1, even though Jason is Anne's close colleague, the social context cannot be propagated between them.

In order to solve these problems, we focus on importing social networks which already exist in other systems, instead of discovering social networks by using data mining tools.

Definition 1 (Social network). A social network SN is given by

$$SN = \langle U, N \rangle \tag{1}$$

where U is a set of users in the social network, and $N \subseteq U \times U$ indicates social links between users.

Thus, we expect that the chances of discovering a social network between people using different telecommunication companies will be increased. We previously mentioned that all possible contexts should be fused, as shown in Fig. 1, so social networks imported from other systems should be efficiently integrated. We refer to this process as *mobilization* of social networks. Therefore, for each user, an *ego-centric* social network has been constructed for the purpose of efficient service provision.

Definition 2 (An ego-centric social network). In this paper, an ego-centric social network of user u can be simply given by

$$SN_u^{\tilde{\epsilon}} = \{SN_i | u \in SN_i\}. \tag{2}$$

It indicates the power set of social networks the user participates in. There should be a method of user identification to establish whether neighbors (i.e., u' and u'') in different social networks are identical (i.e., $u, u' \in SN_i$, $u, u'' \in SN_j$). In this work, we did this manually.

There are a number of possible means to provide mobile services, depending on the strategies and marketing policies of the businesses (e.g., advertisements). In this paper, we show some personalized mobile services based on context matching between users.

The outline of this paper is as follows. In the following Sect. 2, we address an ontology-based context fusion method for heterogeneous contexts extracted from multiple social networks. Sect. 3 shows how to generate recommendations for each user as a mobile service. Also, possible scenarios for the recommendation services are presented. In Sect. 4 and Sect. 5, we presented a case study we conducted for local conferences, and the implications of the case study, respectively. Finally, we draw our conclusions in Sect. 6.

2 Ontology-based context fusion

In this section, we address a context fusion method to integrate contextual evidence that we have collected from social networks. However, a social network has inherently different semantics from other types of network. Such semantic heterogeneity includes not only linguistic differences (e.g., between 'reference' and 'bibliography') but also mismatching between conceptual structures. To deal with these problems, we exploit ontologies from multiple social networks, and more importantly, semantic correspondences obtained by ontology matching methods.

Definition 3 (Ontology). An ontology of a social network SN can be simplified as

$$\mathcal{O}_{SN} = \langle \mathcal{C}, \mathcal{P}, \mathcal{I}, \mathcal{R}_{\mathcal{C}}, \mathcal{R}_{\mathcal{P}} \rangle \tag{3}$$

where $\mathcal{C}$, $\mathcal{P}$, and $\mathcal{I}$ are the sets of concepts, properties, and instances contained in SN, respectively. Also, $\mathcal{R}_{\mathcal{C}} \subseteq \mathcal{C} \times \mathcal{C}$, and $\mathcal{R}_{\mathcal{P}} \subseteq \mathcal{P} \times \mathcal{P}$.

For example, in our previous work [Jung 2008b;Jung et al. 2009], a Social Network Ontology (SNO) has been constructed for representing family relationships (e.g., 'isFatherOf', 'isMotherOf', and so on). Recently, various studies about SNO have been investigated (e.g., [Alani et al. 2009;Erétéo et al. 2009]).

More importantly, the semantics extracted from social networks have already been exploited in many other domains. For example, the DBLP[1] ontology[2] is an ontology for an online bibliographic database system. At this point, we can extract various social relationships (e.g., 'coauthor'), which are not interoperable with SNO from LinkedIn, as shown in Fig. 2.

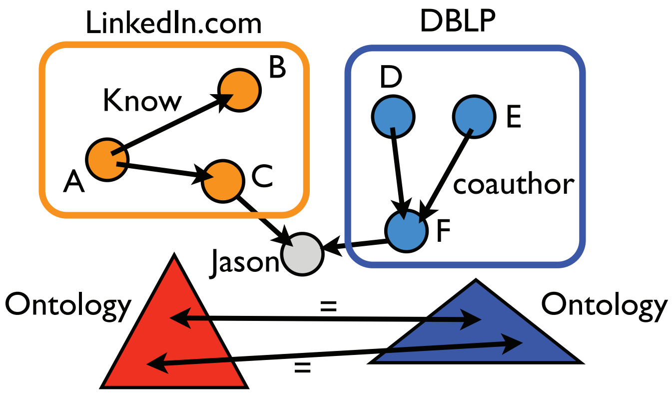

Figure 2: Heterogeneous social network ontologies; $SN_{\text{DBLP}} = \{D, E, F, Jason\}$ and $SN_{\text{LinkedIn}} = \{A, B, C, Jason\}$

In order to solve this semantic heterogeneity problem, we can apply various ontology matching facilities[3]. In practice, such ontologies are already written

[1] http://dblp.uni-trier.de/
[2] http://swat.cse.lehigh.edu/resources/onto/dblp.owl
[3] Ontology matching is not the main contribution of this work. We suggest to refer to [Euzenat and Shvaiko 2007] for more explanation about it.

in OWL[4]. After performing the ontology matching process using software tools [Euzenat and Shvaiko 2007;Jung 2008a], we obtain a set of semantic correspondences between ontology entities (denoted as $CORR$). For example, in Fig. 2, "DBLP:coauthor $\sqsubseteq$ LinkedIn:Know" which refers to the concept "coauthor" in the ontology "DBLP" is a subconcept of the concept "Know" in the ontology "LinkedIn".

We need to take into account how to represent user contexts and how to propagate these contexts along the links in other social networks. To date, many kinds of definitions for these contexts have been proposed [Dey 2001]. User contexts are considered as both personal contexts (e.g., user preferences and interests) and environmental contexts (e.g., temperature and so on). In this study, we focus on the following contexts, i.e., research topics ($CTX^{\mathcal{T}}$) and current location ($CTX^{\mathcal{L}}$).

Additionally, we claim that these contexts can be propagated to other users along social networks. Thus, social networks among users can serve as a channel for sharing context information with other users.

Definition 4 (Social context). Given a user u, a social context can be represented as a set of properties and their scores

$$CTX^{\mathcal{S}}_{u \to u'} = \{\langle p_i, scr_i \rangle | p_i \in \mathcal{O}_{SN_i}, SN_i \in SN_u^{\tilde{\epsilon}}\} \tag{4}$$

where $\mathcal{O}_{SN_i}$ is the SNO in the corresponding user's ego-centric network $SN_u^{\tilde{\epsilon}}$. The score $scr_i \in \{0, 1\}$. Even though there is no direct link between two users, the social context can be efficiently aggregated along the shortest path between users by ontological reasoning [Jung 2009a].

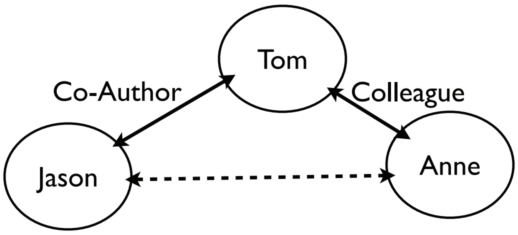

Figure 3: An example of social contexts

More importantly, depending on the social context of the link (or path) between two users, neighbors' contexts can be transformed (or triggered). In

[4] Web Ontology Language (OWL). http://www.w3.org/TR/owl-features/

practice, the score is set to 1 if the social context is positive. We are considering only positive social contexts. For example, in Fig. 3, given two social contexts represented as

$$CTX^{\mathcal{S}}_{\text{Jason}\rightarrow\text{Tom}} = \langle \text{Co-Author}, 1\rangle \text{ and}$$
$$CTX^{\mathcal{S}}_{\text{Tom}\rightarrow\text{Anne}} = \langle \text{Colleague}, 1\rangle,$$

we can find an additional social context as follows;

$$CTX^{\mathcal{S}}_{\text{Jason}\rightarrow\text{Anne}} = \langle \text{Colleague}, 1\rangle \tag{5}$$

where Co-Author $\sqsubseteq$ Colleague.

We present two main measurements to determine whether (and to what extent) a social context is positive in order to establish the influence between users.

- Social (geodesic) distance (denoted as $\mathbb{D}$): This distance can be easily computed by measuring the length of the shortest path between two users. A larger social distance indicates less influence.
- Similarity between social contexts (denoted as $\mathbb{S}$): The similarity between social contexts can be measured by taking into account the matching patterns between the SNOs. The implication is that the influence between two users in different social networks will be higher if their SNOs are more similar. By extending David and Euzenat [David and Euzenat 2008], we obtain

$$\mathbb{S}(u_i, u_j) = \frac{CORR(\mathcal{O}_{SN_i}, \mathcal{O}_{SN_j})}{\max(|\mathcal{O}_{SN_i}|, |\mathcal{O}_{SN_j}|)} \tag{6}$$

  where $\mathcal{O}_{SN_i}$ and $\mathcal{O}_{SN_j}$ are the SNOs by the two users, respectively. Also, $|\mathcal{O}|$ means the set of the ontology (i.e., the total number of only concepts and properties). The range of the similarity is $[0, 1]$.

These two heuristic factors (i.e., $\mathbb{D}$ and $\mathbb{S}$) are applied to integrate the social contexts retrieved from the social networks.

Definition 5 (Fused context). A fused context of a user u can be obtained by using two heuristics $\mathbb{D}$ and $\mathbb{S}$. There are three different formulations, as follows;

$$FCTX_u = \sum_{u',u''\in SN_u^{\bar{\epsilon}}} \mathbb{F}(CTX_{u'}, CTX^{\mathcal{S}}_{u\rightarrow u''}) \tag{7}$$

$$= \sum_{u',u''\in SN_u^{\bar{\epsilon}}} \mathbb{F}\left(CTX_{u'}, \frac{CTX^{\mathcal{S}}_{u\rightarrow u''}}{\mathbb{D}(u,u'')}\right) \tag{8}$$

$$= \sum_{u',u''\in SN_u^{\bar{\epsilon}}} \mathbb{F}(CTX_{u'}, CTX^{\mathcal{S}}_{u\rightarrow u''} \times \mathbb{S}(u,u'')) \tag{9}$$

where u' and u'' are the users linked to u directly and indirectly, respectively. The function $\mathbb{F}$ means a simple set union operator.

As mentioned in [Hofreiter et al. 2005;Bessai et al. 2008;Jung et al. 2009], there are a number of possible fusion functions, depending on the business policies and strategies. We discuss a simple rule-based fusion method in the next section with a case study.

3 Mobile services by social contexts: a case study

The fused context has been obtained by mobilizing social networks. We must then discuss how to exploit the context information for providing efficient services. In this section, we focus on applying the fused contexts to a mobile recommendation service with a case study.

Assume that an academic conference has several sessions in parallel. Various types of mobile services can be useful to the conference participants. We note the following potential scenarios.

Scenario 1 (Personalized scheduling.) *When conference participants have registered, they receive full information about the conference. However, because such information is not personalized, they must decide whether each presentation (or session) is relevant to their own research topics. The fused context of each participant is comprised of their previous and recent publications and research projects. Moreover, their scholar (or coauthor) networks can be applied to enhance the fusion process, and then, the fused context can be exploited to make a comparison with a set of keywords from the papers.*

Scenario 2 (Location-based service.) *This conference is also an important chance for social interaction between the scientists. However, it is difficult to find and meet a specific person during the sessions and social events. A fused context can include current location information by RFID tags or smart cards as well as coauthor networks, similar to the previous scenario. Thus, the participants can be efficiently informed of the location of the person they are seeking.*

Scenario 3 (Social network management.) *Even though participants have active social interactions with others in the conference, it is difficult to remember all of them without exchanging business cards. From the fused contexts, we can measure adjacency patterns among participants by using RFID tags or smart cards. The patterns are stored and merged into their own online social network systems, so that they can easily manage their social networks.*

4 Experimentation

To evaluate the proposed system, we have implemented a smart conference system with RFID tags for all participants and RFID readers in all conference rooms. The proposed system has been used in two Korean domestic conferences in 2009. The numbers of participants in these conferences were 104 and 85, respectively. During registration, all the participants were asked to input their affiliation, OpenID[5], email address, and all accounts of major social networking systems currently used by them. Social network datasets have been collected from online social networking systems as well as offline social network activities. All of the data sources are shown below.

- Online social networks
  1. (SN_1) FaceBook (http://www.facebook.com/)
  2. (SN_2) Twitter (http://twitter.com/)
  3. (SN_3) Cyworld[6] (http://cyworld.com/)
  4. (SN_4) DBLP (http://www.informatik.uni-trier.de/ ley/db/)
  5. (SN_5) CiteSeer (http://citeseer.ist.psu.edu/)
  6. (SN_6) Korean DBPIA (https://www.dbpia.com/)
- Offline social networks
  1. (SN_7) Affiliation
  2. (SN_8) Address

Through these user inputs, we have constructed the ego-centric social network of each participant. Especially, DBLP, CiteSeer and DBPIA ontologies have been automatically matched with each other by OLA[7]. In practice, the OpenID and email address information could easily be used to detect the redundant participants with multiple accounts.

Table 1: Performance of mobile recommendation at the first conference (%)

	with Eq. 7			with Eq. 9		
Parallel sessions	Session 1	Session 2	Session 3	Session 1	Session 2	Session 3
Morning	82.44	60.54	62.01	93.2	70.75	70.25
Afternoon 1	56.17	46.26	68.66	83.5	79.8	69.4
Afternoon 2	65.95	37.67	48.79	86.35	72.5	85.0

[5] http://openid.net/
[6] CyWorld is one of the most popular social network systems in Korea.
[7] OWL-Lite Alignment [Euzenat 2004]. http://ola.gforge.inria.fr/

Table 2: Performance of mobile recommendation at the second conference with Eq. 9 (%)

Parallel sessions	Session 1	Session 2	Session 3	Session 4
Morning	68.95	85.3	91.2	85.5
Afternoon 1	84.24	77.95	79.33	89.4
Afternoon 2	84.3	89.25	84.5	85.25

During the conferences, the participants occasionally received text messages via their cell phones. We have focused on providing the following three mobile services to the participants and also evaluated them to establish the effectiveness of the services by measuring user satisfaction;

Recommendation of presentation schedule We have used a simple string matching between all papers (i.e., only keywords) in the conference proceedings and the fused contexts (i.e., $CTX^{\mathcal{T}}$) from SN_4, SN_5, and SN_6 with Eq. 7 and Eq. 9. For evaluation, we have computed the ratio of participants who acted according to the recommendation provided from the proposed system. We could easily determine which sessions were attended by the participants by referring to the RFID log database. The two one-day conferences were organized into 3 and 4 parallel sessions, as shown in Table 1 and Table 2.

Recommendation of potential users Because we wanted the participants to interact as much as possible, we sent the location of a particular participant to potential users during the coffee breaks and banquet. The contexts from SN_1, SN_2, SN_3, SN_4, SN_7, and SN_8 have been fused by three different methods Eq. 7, Eq. 8 and Eq. 9. For evaluation, we asked the participants to reply via SMS if they encountered potential colleagues working on common research topics. The ratio of replies to recommendations has been measured at the conferences, as shown in Table 3. Furthermore, the time difference between the timestamps has been computed.

Table 3: Ratio of replies about recommending potential colleagues

	Eq. 7	Eq. 8	Eq. 9
Conference1	59.3% (= 51/86)	80.8% (= 42/52)	85.1% (= 40/47)
Conference2	60.3% (= 41/68)	78.3% (= 18/23)	85.3% (= 29/34)

5 Discussion and related work

We implemented two mobile services in academic conferences, and collected experimental results. The the first service recommending personalized schedules, we compared two groups of participants by using two different context fusion methods. We found that recommendations based on Eq. 9 outperform those based on Eq. 7 by 40.3%. Overall, the average performances of the recommendation services at those conferences were 78.97% and 83.76%, respectively. We infer that the social contexts extracted from the bibliographic social networks (i.e., DBLP, DBPIA, and CiteSeer) have been useful to compare contexts about research topics.

Secondly, in terms of recommending potential social colleagues, the similarity between social contexts (i.e., $\mathbb{S}$ in Eq. 9) has been the most useful information for context fusion. Also, such potential social links have enriched online ego-centric social networks to foster efficient social collaborations between potential users.

For the third issue, we discuss the privacy problem for online users. In this work, we have tried to collect all possible social networks from multiple sources both online and offline. Because such social network information is already open and is published on the sources, we have assumed that the network integration process does not invade user privacy. Moreover, the services provided by this system can be called *implicit* recommendation, because the system does not disturb users by asking whether the obtained results are correct or not.

There have been several studies related with this work. In [Cabri et al. 2003], social contexts between users have been applied to generate mobile recommendations. Sych contexts were simply assumed to be declared by all users. Extended reality mining schemes [Eagle and Pentland 2006;Jung et al. 2009] have been proposed to discover social contexts by analyzing user behaviors in mobile environments. Such recommendation services have been exploited in various domains. In the CSCW area, a context-based collaborative working environment has been configured in [Gross and Prinz 2004;Edwards 2005]. Also, a context-based collaborative learning system [Yang 2006] has been developed for the e-learning domain.

6 Conclusion

This section presents our conclusions. In this paper, we have focused on context propagation to social networks. It means that the user activities are dependent on the contexts of their neighbors. The main contribution of this work is to exploit the correspondences between ontologies from multiple sources for context fusion in an ego-centric social network. Given heterogeneous contexts extracted from multiple social networks, we need a context fusion process which can find the hidden relationships between the contexts.

From the experiments for both mobile services, we have found that the SNO-based matching was an effective means to discover meaningful social relationships between the mobilized online social networks.

In future work, we are planning to deal with the following issues;

- Detecting dynamic changes of user contexts. We have to consider that the user contexts can be changed over time. Thus, there should be an efficient facility to detect significant differences between contexts.
- Uncertainty reasoning for social context fusion. The proposed heuristics (i.e., Eq. 7, Eq. 8, and Eq. 9) need to be improved by considering uncertainties in the social networks.
- Scalability testing. A large-scale social network is an important challenge for context-based recommendation [Gangemi 2008]. We are planning to apply a query sampling method [Jung 2009b] to collect only contextually relevant users.
- Trust and reputation management [Jung 2009d]. We have to consider trustworthy recommendation services. Sometimes, there are malicious users and activities on the social network, which can make the social contexts distorted and polluted.
- Developing a social network among businesses [Jung 2009c]. Finally, it is also important to apply the social network integration method to business networks, as the relationships and dependencies between businesses are getting more complex.

Acknowledgement

This work was supported by the National Research Foundation (NRF) grant funded by the Korean government (MEST) (No. 2009-0066751).

References

[Alani et al. 2009] Alani, H., Szomszor, M., Cattuto, C., can den Broeck, W., Correndo, G., and Barrat, A.: Live social semantics. In Bernstein et al. (eds), *Proceedings of the 8th International Semantic Web Conference (ISWC 2009), Chantilly, VA, USA, October 25-29*, volume 5823 of *Lecture Notes in Computer Science*, pages 698–714. Springer, 2009.

[Bessai et al. 2008] Bessai, K., Claudepierre, B., Saidani, O., and Nurcan, S.: Context-aware business process evaluation and redesign. In Nurcan et al. (eds), *Proceedings of the 9th Workshop on Business Process Modeling, Development and Support in conjunction with the CAiSE'08 conference Montpellier, France, June 16-17*, 2008.

[Cabri et al. 2003] Cabri, G., Leonardi, L., Mamei, M., and Zambonelli, F.: Location-dependent services for mobile users. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, 33(6):667–681, 2003.

[David and Euzenat 2008] Jérôme David and Jérôme Euzenat. Comparison between ontology distances (preliminary results). In Sheth et al. (eds), *Proceedings of the 7th International Semantic Web Conference (ISWC 2008), Karlsruhe, Germany*, volume 5318 of *Lecture Notes in Computer Science*, pages 245–260. Springer, 2008.
[Dey 2001] Dey, A.K.: Understanding and using context. *Personal and Ubiquitous Computing*, 5(1):4–7, 2001.
[Eagle and Pentland 2006] Eagle, N., and Pentland, A.: Reality mining: sensing complex social systems. *Personal and Ubiquitous Computing*, 10(4):255–268, 2006.
[Edwards 2005] Edwards, W.K.: Putting computing in context: An infrastructure to support extensible context-enhanced collaborative applications. *ACM Transactions on Computer-Human Interaction*, 12(4):446–474, 2005.
[Erétéo et al. 2009] Erétéo, G., Buffa, M., Gandon, F., and Corby, O.: Analysis of a real online social network using semantic web frameworks. In Bernstein et al. (eds), *Proceedings of the 8th International Semantic Web Conference (ISWC 2009), Chantilly, VA, USA, October 25-29*, volume 5823 of *Lecture Notes in Computer Science*, pages 180–195. Springer, 2009.
[Euzenat 2004] Jérôme Euzenat. An API for ontology alignment. In McIlraith et al. (eds), *Proceedings of the 3rd International Semantic Web Conference*, volume 3298 of *Lecture Notes in Computer Science*, pages 698–712. Springer, 2004.
[Euzenat and Shvaiko 2007] Euzenat, J., and Shvaiko, P.: *Ontology matching*. Springer, Heidelberg, Germany, 2007.
[Gangemi 2008] Gangemi, A.: Norms and plans as unification criteria for social collectives. *Autonomous Agent and Multi-Agent Systems*, 17(1):70–112, 2008.
[Gross and Prinz 2004] Gross, T., and Prinz, W.: Modelling shared contexts in cooperative environments: Concept, implementation, and evaluation. *Computer Supported Cooperative Work*, 13(3):283–303, 2004.
[Hofreiter et al. 2005] Hofreiter, B., Huemer, C., and Winiwarter, W.: Business collaboration models and their business context-dependent web choreography in BPSS. *International Journal of Web Information Systems*, 1(1):33–42, 2005.
[Jung 2008a] Jung, J.J.: Ontology-based context synchronization for ad-hoc social collaborations. *Knowledge-Based Systems*, 21(7):573–580, 2008.
[Jung 2008b] Jung, J.J.: Query transformation based on semantic centrality in semantic social network. *Journal of Universal Computer Science*, 14(7):1031–1047, 2008.
[Jung 2009a] Jung, J.J.: Contextualized mobile recommendation service based on interactive social network discovered from mobile users. *Expert Systems with Applications*, 36:11950–11956, 2009.
[Jung 2009b] Jung, J.J.: Contextualized query sampling to discover semantic resource descriptions on the web. *Information Processing & Management*, 45(2):283–290, 2009.
[Jung 2009c] Jung, J.J.: Semantic business process integration based on ontology alignment. *Expert Systems with Applications*, 36(8):11013–11020, 2009.
[Jung 2009d] Jung, J.J.: Trustworthy knowledge diffusion model based on risk discovery on peer-to-peer networks. *Expert Systems with Applications*, 36(3):7123–7128, 2009.
[Jung et al. 2009] Jung, J.J., Lee, H., and Choi, K.S.: Contextualized recommendation based on reality mining from mobile subscribers. *Cybernetics and Systems*, 40(2):160–175, 2009.
[Yang 2006] Yang, S.J.H.: Context aware ubiquitous learning environments for peer-to-peer collaborative learning. *Educational Technology & Society*, 9(1):188–201, 2006.