Integrating Pervasive Middleware with Social Networks in SAPERE

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***Abstract*—Any middleware for pervasive computing services has to effectively support both spatially-situated activities and social models of interactions. In this paper, we present the solution integrated in the tuple-based SAPERE middleware to tackle this problem. The idea is to exploit the graph of a social network along with relations deriving from spatial proximity to rule the actual topology of interactions among devices, users and services. The proposed approach can facilitate the autonomous and adaptive activities of pervasive services while accounting for both social and spatial issues, can support effective service discovery and orchestration, and can enable tackling critical privacy issues.**

I. Introduction

The spread of pervasive computing technologies, smart phones above all [1], is leading to the emergence of an integrated and very dense socio-technical infrastructure for the provisioning of innovative general-purpose digital services [2], [3]. That infrastructure will be used to ubiquitously access services for better interacting with the surrounding physical world and with the social activities occurring in it. Also, the infrastructure will be very open, enabling users to deploy customized services and to make available own devices.

The overall ambitious goal of the EU funded SAPERE Project ("Self-aware Pervasive Service Ecosystems", www.sapere-project.eu) is to define an innovative theoretical and practical framework to support the development and execution of adaptive pervasive services, in which the typical problems of pervasive environments (i.e., accounting for spatiality, self-adaptivity and self-management, context-awareness, and social-awareness), can all be tackled in a uniform an integrated way. To this end, in SAPERE, we are working towards the implementation of a distributed middleware infrastructure to enable adaptive and open execution of complex pervasive services. The middleware is grounded on an innovative nature-inspired and distributed coordination model, i.e., relying on spatially-situated and chemically-inspired interactions between services and devices, to promote spatial self-adaptivity and self-management.

Turning the necessarily abstract concept of space of the model into a practical and usable reification means strive for something: *(i)* implementable and capable of flexibly matching the actual characteristics of pervasive applications, whose components may have to interact based on physical relations; and *(ii)* supporting the need for users to interact, and based on their social relations and in respect of privacy issues, facilitating services/devices interaction and composition based on such social relations, other than simply based on spatial proximity.

The solution we have recently integrated in the SAPERE middleware – and which is the specific focus of this paper – exploits in a synergetic way the spatial relations between users, devices and services (as deriving from physical proximity) with the awareness of social relations as they can be expressed in some social networks (e.g., Facebook). In particular: *(i)* the physical proximity between the nodes of the distributed infrastructure of the SAPERE middleware (including smart phones and infrastructural servers) defines the topology of the SAPERE network, and shapes the distributed spatial coordination activities of the middleware; *(ii)* both smart phones and infrastructural servers are associated to a profile in a social network (e.g., Facebook); *(iii)* for two SAPERE nodes, the actual sharing of sensing information as well as the discovery and composition of services residing on those nodes, is enabled by physical proximity but is subject to the existence of a social relation between the two nodes.

As we will discuss in this paper, the approach is very effective to harness the power of social networks in the context of spatially situated pervasive services. In particular: it makes possible to promote and control adaptive interactions taking into account both spatial and social concerns; it facilitates service discovery and composition relying on the social relations between services; it makes it possible to express complex spatial relations between nodes by acting on the social network graph; finally, it enables handling and controlling privacy issues very effectively.

The remainder of this paper is organized as follows. Section 2 discusses related approaches. Section 3 describes the model behind the SAPERE middleware and the current implementation. Section 4 details our approach for integrating social networks in the SAPERE middleware. Section 5 discusses the advantages and the limitations of the approach. Section 6 concludes and sketches future work.

II. Related Approaches

The idea that social aspects and social awareness are highly relevant for the effective realization of pervasive computing services is not new indeed [4]. However, several proposals in the area attack the problem only from the perspective of exploiting pervasive computing services to detect social relationships and to enable sharing of social experiences [4], [5], [6], [7]. Rather, our approach starts from the idea that to support social models of interaction, the middleware could effectively exploit the large body of social awareness already embedded in social networking tools.

Also in the area of service-oriented computing it is getting recognized that social networking can notably facilitate, or make more reliable and trustable, service discovery and composition [8], [9], [10]. For instance, in the LinkedWS proposal [11], a social network of services is dynamically built by analyzing the patterns of co-invocation and similarity, and defining the social relationships between services accordingly to those patterns. Then, the discovery of Web services can be notably facilitated by "navigating" the resulting social network of services to, e.g., discover the most suitable partners for a composition or recommend alternatives between equivalent services. In our approach, other than focussing on the scenario of pervasive computing rather than on Web services, we exploit social networks of users to seamlessly integrate in it a social network of services and devices.

The proposal described in [12] is the one that more closely relates to our. The approach shares our idea that the awareness hidden in social networks about "who trust who" can be effectively exploited to promote discovery and sharing among personal sensors. To this end, an extended social network concept is introduced that, for each user, includes a "circle" of personal devices and services of the user. On this basis, a user can specify which of its own resources (services and devices) to share with friends or groups. Our approach shares similar assumptions, but goes further, by suggesting that the social network has not only to promote sharing of devices and services, but has to be embedded at a deeper level in a pervasive middleware, to define the very structure of "space" in which interactions take place.

III. THE SAPERE MIDDLEWARE

SAPERE takes its primary inspiration from natural ecosystems and aims to model the overall world of services, data, and devices as a sort of distributed and spatially-situated computational *ecosystem*. However, unlike the many proposals that adopt the term ecosystem simply as a mean to characterize the complexity and dynamics of ICT systems [13], SAPERE brings the adoption of natural metaphors down to the core of its approach, by exploiting nature-inspired mechanisms (and in particular bio-chemical ones [14]) for actually ruling the overall system dynamics.

A. The Grounding Model

SAPERE models a pervasive service environment as a *spatial substrate*, laid above the actual pervasive network infrastructure (see Figure 1). The substrate embeds the basic laws of nature (or *eco-laws*) that rule the activities of the system. It represents the ground on which individuals of different species (i.e., the components of the pervasive service ecosystem) interact and combine with each other (in respect of the eco-laws and typically based on their spatial relationships), so as to serve their own individual needs as well as the sustainability of the overall ecology. Users can access the ecology in a decentralized way to use and consume data and services, and they can also act as "prosumers" by injecting new data or service components.

For the *components* living in the ecosystem, SAPERE adopts a common modeling and treatment of services, data, and devices. All "entities" living in the ecosystem will have an associated semantic representation which is a basic ingredient for enabling dynamic unsupervised interactions between components. To account for the high dynamics of the scenario and for its need of continuous adaptation, SAPERE will define such annotations as living, active entities, tightly associated to the component they describe, and capable of reflecting its current situation and context. Such *Live Semantic Annotations* (LSAs) will thus act as observable interfaces of resources and services, as well as the basis for enforcing semantic and self-aware forms of dynamic interactions.

For the *eco-laws* driving the dynamics of the ecosystem, SAPERE envisions them to define the basic policies to drive virtual *chemical reactions* among the LSAs of the various individuals of the ecology [15], [14]. In particular, the idea is to enforce, on a spatial basis and possibly relying on diffusive spatial mechanisms [16], dynamic networking and composition of data and services. In particular, data and services (as represented by their associated LSAs) will be sort of chemical reagents, and interactions and compositions will occur via chemical reactions, i.e., semantic pattern-matching, between LSAs. Such reactions will contribute establishing virtual chemical bonds between entities (e.g., bonding similar services in a distributed service) as well as producing new components. (e.g. an high-level knowledge concept derived from the aggregation of raw data items).

Adaptivity in SAPERE will not be in the capability of individual components, but rather in the overall dynamics of the ecosystem. In particular, adaptivity will be ensured by the fact that any change in the system will reflect in the firing of new chemical reactions, thus possibly leading to the establishment of new bonds and/or in the breaking of some existing bonds between components.

B. The Current Implementation

From an implementation viewpoint, SAPERE relies on a minimal middleware infrastructure (see Figure 2)

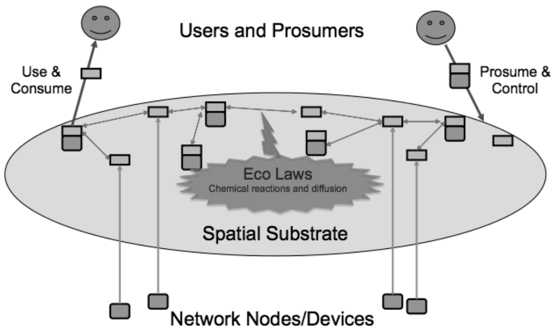


Figure 1. The SAPERE Model

lightweight enough to be hosted even in Android smart phones and tablets.

The SAPERE middleware reifies LSAs in the form of tuples, dynamically stored and updated in a system of highly-distributed tuple spaces spread over the nodes of the network. In particular, LSA tuple spaces are currently implemented using an enhanced version of TUCSON [14].

The active components of the ecosystem (whether services, sensing/actuating devices, or data sources) express their existence via LSAs injected in the local tuple space associated to their node. Then, they indirectly interact with each other via such tuple space by observing and accessing the LSAs there stored.

The eco-laws represent sorts of virtual chemical reactions between LSAs, and get activated by processes embedded in tuple spaces (which makes SAPERE tuple spaces different from traditional tuple spaces). Such processes evaluate the potentials for establishing new chemical bonds between LSAs, the need for breaking some, or the need for generating new LSAs from the combination of existing ones.

In addition, to support distributed spatial interactions, the network of tuple spaces is assumed to have a defined topology, defining neighborhood relations between tuple spaces. The issue of shaping such topology will be discussed in the following subsection.

On the basis of the topology of the tuple spaces networks, eco-laws can enforce the diffusion of LSAs to spatially close tuple spaces, according to specific propagation patterns (gradient-based diffusion, broadcast, or multicast). In the current implementation, eco-laws are realized in terms of programmable TUCSON reactions. However, a new tuple space engine, specifically conceived to support SAPERE eco-laws is under implementation.

C. Shaping the SAPERE Network

The SAPERE model refers generically to a spatial substrate, which abstracts away from actual networking considerations as well as from social considerations. Similarly, in the presentation of the SAPERE middleware so far, we stated that the solution to make such spatial concept practical is to map it into a network space, a network of nodes each hosting a tuple space and in which the concept of spatial proximity turns into a concept of network neighborhood. However, the issue arises of actually giving shape to such network and make it correspond to some useful, usable, and adaptive spatial notion.

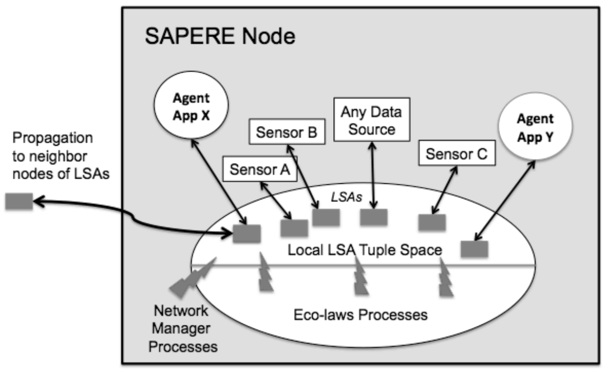


Figure 2. The SAPERE Middleware on a Node of the Network.

In SAPERE, to preserve generality, we have decided not to embed any specific solutions at the level of eco-laws. Rather, we have associated specific configurable processes – configurable at launch time – hosted in the LSA tuple spaces to act as network topology managers. Network topology managers have the exact goal of establishing and maintaining in an adaptive way the topology of the network according to some specific policies, among the many possible ones.

The spatial policies that SAPERE network topology managers can support are the *network-driven* and the *map-driven* one, in addition to the new one based on social networks that overcomes the limitations of the former two.

The network-driven policy considers shaping the SAPERE network on the basis of the existence of wired or wireless network connections between nodes to define the neighborhood relations. Such solution directly maps the network topology into a spatial topology, because connections reflect spatial proximity. The problems with such solution, though, are that: *(i)* the solution works well and in a very adaptive way for wireless mobile devices but it is not suitable to handle infrastructural and ambient nodes (e.g., an interactive display in a meeting room), calling for specific a priori configuration effort; *(ii)* the solution sometimes introduces mismatches between the actual physical proximity and the logical or social proximity (e.g., two nodes can be physically very close but in different sections of a building).

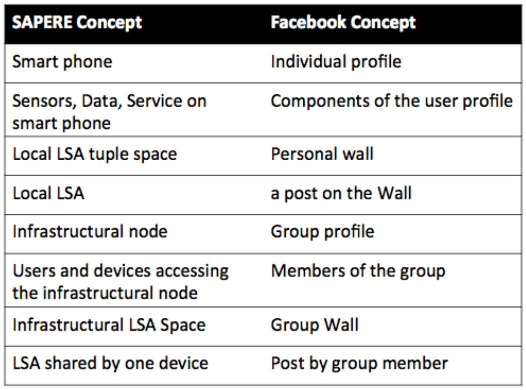
The map-driven solution considers that nodes access some existing representation of space, e.g., a map, logically locate themselves on the map (e.g., using GPS), and select their neighbors accordingly (e.g., node A in room X defines itself neighbor with node B in corridor Y). Such solution could also be possibly coupled with the network-driven one (e.g., two nodes are neighbors if they are in wireless range and logically close in the map). The problems of the map-driven solution are that: *(i)* it requires a priori information about the environment as SAPERE nodes need to know how to access the map of a location, also configuration actions must take place to keep the map up-to-date; *(ii)* the solution works well for infrastructural SAPERE nodes to connect with logically close users/devices, however it forces users to share logical locations, which may not always be acceptable for security and privacy; *(iii)* the solution does not account for the social relations between users or between users and the space in which they locate.

IV. Integrating Social Networks in SAPERE

The new and sounder solution we have implemented merges the physical proximity concept of the network-driven solution with a map-driven solution in which social networks (SNs) are exploited to act as social maps. That is, given the possibility for SAPERE nodes to access the graph of some existing SNs: two SAPERE nodes are actual neighbors if they are neighbors according to both the network viewpoint and the social map viewpoint. Comparing to the network-driven and to the map-driven solutions:

- SNs already exist and are getting frequently accessed by their users. So, there is not need to organize repositories of maps and let SAPERE nodes be acknowledged on how to access them.
- SNs are continuously updated with new information and relations based on the willingness of participants to share new and updated information, so that information is to be considered *by definition* up-to-date, which is very important to effectively support adaptivity.
- Relations in SNs can be social (friendship between two users) but also spatial (e.g., a social group representing some logical place, such as a a classroom or a department), which opens the possibility of representing both logical spatial relations and social ones with a single tool.
- The solution tolerates a nearly uniform treatment of mobile nodes and infrastructural nodes, both of them being nodes of the SAPERE network and nodes of the social network.

For the sake of simplicity, we will refer in the following to Facebook and to its specific terminology. The basic assumption is that all SAPERE nodes are associated to a profile in a social network, whether an individual profile (for mobile phones) or a group one (for infrastructural nodes). Figure 3 shows how the already presented SAPERE concepts can be made directly corresponding to Facebook concepts. In any case, since accesses to the social network are performed by the configurable network manager processes, it is possible to re-configure at very low costs the middleware to exploit any other social networking tools (e.g., Google+ or LinkedIN) having an open API.



SAPERE Concept	Facebook Concept
Smart phone	Individual profile
Sensors, Data, Service on smart phone	Components of the user profile
Local LSA tuple space	Personal wall
Local LSA	a post on the Wall
Infrastructural node	Group profile
Users and devices accessing the infrastructural node	Members of the group
Infrastructural LSA Space	Group Wall
LSA shared by one device	Post by group member

Figure 3. SAPERE vs. Facebook Concepts.

A. Interactions Between Smart Phones

For smart phones, the sensing devices on the phone, the data inputed by the user or any data source of the phone, as well as those software agents/services/applications executing on the phone, have each an LSA associated in the local LSA tuple space.

All such components are part of the overall user profile in the social network, and it is up to the user to set up the sharing rules for these: which services/data/devices to share which other members or group of the social network. Sharing, in particular, implies the possibility of propagating LSAs to neighbor nodes, and thus initiating SAPERE-style interactions with other nodes. To some extent, the Local LSA space can be assimilated to the personal user wall for services and devices.

The network topology manager on a smart phone is in charge of verifying the state of the wireless network connections and of the social network (e.g., Facebook) relations to shape the actual topology of the SAPERE network.

As from Figure 4, as soon as the topology manager on a node perceives it is in wireless range with some other node, it accesses the social network (e.g., by exploiting the Graph Facebook API) to verify the existence of a friendship relations between the owners of the two nodes. If so, the two nodes are considered neighbors from the SAPERE topology viewpoint, and LSA propagation between these two nodes can start.

Clearly, such LSA propagation involves those active agents/services/applications that require distributed coordination. For those cases, the effect of LSA propagation is to enable exchange of information between the nodes (in the form of LSAs) and to trigger virtual chemical reactions that can lead to compose and orchestrate the activities of the distributed services and devices on such mobile phones.

In any case, such propagation of LSAs, and consequently the interactions they trigger, are conditional upon the privacy setting that, for the individual devices and services, the user has set up on his social network profile (settings that it is up to the network topology manager to check).

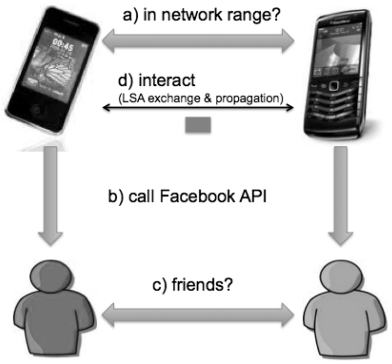


Figure 4. Interactions between friends.

B. Interactions Between Smart Phones and Infrastructural Nodes

All infrastructural nodes are assumed to have a group profile on the social network, even corresponding to some general social group, unrelated to space. However a group basically represents the logical space in which the infrastructural node is located (e.g., the group of the services provided in the meeting room X). Individual users (and their mobile phones) can subscribe to the group to participate in the local ambient services promoted by the infrastructural node.

For an infrastructural SAPERE node, the local LSA tuple space of the node acts indeed as a sort of shared LSA space for all the members of the group. The idea is that once a mobile SAPERE node gets in range with some infrastructural node (see Figure 5), the membership of the node to the group is verified by the network topology manager.

In particular, it is also possible for a mobile node to be asked to join the group dynamically, and even to dynamically download on the mobile phone specific applications/services that will enable the user to exploit at the best the fact of being in that location, i.e., of enabling the proper coordination activities with the infrastructural SAPERE node.

As soon as a mobile node enters a group, its own LSAs can get propagated to the shared LSA of the infrastructural node, and vice versa, to have interactions starting. As discussed in the previous subsection, it is up to the user to decide which LSAs to share with groups.

To promote the exploitation of logical spatial concepts in pervasive services, we consider that groups, at their turn, can subscribe to each other. This makes it possible to define relations between infrastructural SAPERE nodes, and to reflect spatial relations between the locations they represent (e.g., for two confining rooms). As for interactions between infrastructural nodes, these again rely on LSAs propagation and inter-node chemical coordination for those nodes whose groups are members of each other.

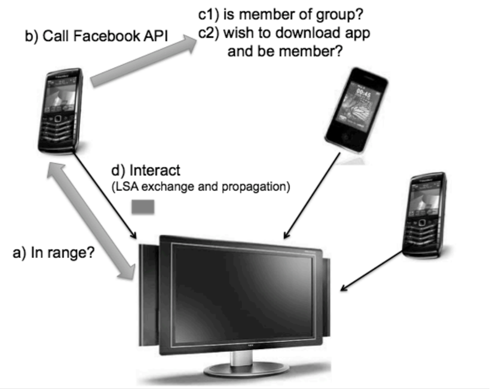


Figure 5. Interactions in a group.

V. PROS AND CONS OF THE APPROACH

The proposed approach has some key advantages.

It couples the capability of shaping of the network topology based on spatial considerations with the capability of adapting the actual shape of such topology based on social considerations. This allows for services that are at the same time adaptive to both social and spatial concerns. Also, by acting on the structure of the social graph, those adaptive interactions can be controlled and shaped on-the-fly, without requiring re-configuration of the service, components and devices.

Service discovery and composition is made more effective due to the possibility of selecting services (or devices) depending on the logical (e.g., social) relations, between services, other than simply in terms of physical proximity. That is, when based on LSAs propagation the SAPERE eco-laws trigger the composition of some services, such composition has not to deal with accounting for a large mass of components, but only with those who are related on the social network, an advantage that is being recently recognized also in the area of service-oriented architectures [10].

The approach makes it possible to express higher-level spatial relations than simply metric ones (e.g., spatial proximity), by exploiting the social network graph (and in particular relations between groups) to represent logical spatial concepts (e.g., the map of a building) and by having spatial coordination activities being shaped by such logical spatial relations.

By acting on the social network profile, the handling of privacy issues by users and ambient administrators (i.e., which information and services to share with which users and ambients) can be notably facilitated, made more transparent, and more controllable.

However, the proposed approach has also some disadvantages and limitations that we are currently trying to address:

Existing APIs for social networks tend to be very slow, mainly as a trick to protect massive data extraction from them, which slows down interactions in our approach. Nevertheless, we think that future social networks will necessarily have to account for the need of social networking of services and devices, and will support faster APIs to this purpose.

The approach assumes the existence of a network of social relations that has been defined independently of pervasive interactions. However, social networks change dynamically and it is expected that pervasive interactions between users will contribute introducing even higher-levels of dynamics in social networks. Thus, the problem will arise of how to manage the inter-play between the level of pervasive interactions and the social network level, in particular as far as the dynamics induced by the pervasive spatial level on the social network level are involved.

VI. Conclusions and Future Work

In this paper we have presented the approach that we have implemented in the SAPERE middleware to promote socially-enhanced spatial interactions in pervasive computing services. The basic idea is to integrate the physical space of interactions with a social networking graph, so as to facilitate the autonomous and adaptive activities of pervasive services while accounting for social and spatial issues at the same time.

Our current work includes performing tests related to the overhead of our early implementation and developing several applications to challenge the idea in the real-world. In addition, we are planning to extend our approach to: include social recommendations in service composition [17] and to leverage users' posts as sensing devices [18].

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References

[1] N. D. Lane, E. Miluzzo, H. Lu, D. Peebles, T. Choudhury, and A. T. Campbell, "A survey of mobile phone sensing," *IEEE Communications Magazine*, vol. 48, no. 9, pp. 140 – 150, September 2010.

[2] G. Olson, G. Mark, E. Churchill, and D. Rotman, "New missions for a sociotechnical infrastructure," *IEEE Computer*, vol. 43, pp. 37–43, 2010.

[3] F. Zambonelli, "Pervasive urban crowdsourcing: Visions and challenges," in *5th International PerCom Workshop on Pervasive Life, Learning, and Leisure*. IEEE CS Press, March 2011.

[4] P. Markopoulos, "Awareness systems and the role of social intelligence," *Artificial Intelligence and Society*, vol. 24, pp. 115–122, 2009.

[5] P. Hui, J. Crowcroft, and E. Yoneki, "Bubble rap: Social-based forwarding in delay tolerant networks," *IEEE Transactions on Mobile Computing*, 2011.

[6] C. Boldrini, M. Conti, F. Delmastro, and A. Passarella, "Context- and social-aware middleware for opportunistic networks," *Journal of Network and Computer Applications*, vol. 33, no. 5, pp. 525–541, 2010.

[7] K. Zhu, P. Hui, Y. Chen, X. Fu, and W. Li, "Exploring user social behaviors in mobile social applications," in *Proceedings of the 4th Workshop on Social Network Systems*. New York, NY, USA: ACM, 2011, pp. 3:1–3:6.

[8] X. Xie, B. Du, and Z. Zhang, "Semantic service composition based on social network," in *17th International World Wide Web Conferece, Beijing (CH)*, 2008.

[9] U. Kuter and J. Golbeck, "Semantic web service composition in social environments," in *8th International Semantic Web Conference, Chantilly (VA)*, October 2009, pp. 344–358.

[10] Z. Maamar, H. Hacid, and M. Huhns, "Why web services need social networks," *Internet Computing, IEEE*, vol. 15, no. 2, pp. 90 –94, march-april 2011.

[11] Z. Maamar, L. K. Wives, Y. Badr, S. Elnaffar, K. Boukadi, and N. Faci, "Linkedws: A novel web services discovery model based on the metaphor of "social networks"," *Simulation Modelling Practice and Theory*, vol. 19, no. 1, pp. 121–132, 2011.

[12] N. Esfahani and S. Malek, "Social computing networks: a new paradigm for engineering self-adaptive pervasive software systems," in *Proceedings of the 32nd ACM/IEEE International Conference on Software Engineering, Cape Town, South Africa*. ACM, May 2010, pp. 159–162.

[13] M. Ulieru and S. Grobbelaar, "Engineering industrial ecosystems in a networked world," in *5th IEEE International Conference on Industrial Informatics*. IEEE Press, June 2007, pp. 1–7.

[14] M. Viroli, M. Casadei, S. Montagna, and F. Zambonelli, "Spatial coordination of pervasive services through chemical-inspired tuple spaces," *ACM Transactions on Autonomous and Adaptive Systems*, vol. 6, no. 2, p. 14, 2011.

[15] J.-P. Banâtre and T. Priol, "Chemical programming of future service-oriented architectures," *Journal of Software*, vol. 4, no. 7, pp. 738–746, 2009.

[16] M. Mamei and F. Zambonelli, "Programming pervasive and mobile computing applications: the tota approach," *ACM Trans. Software Engineering and Methodology*, vol. 18, no. 4, 2009.

[17] G. Castelli, M. Mamei, and F. Zambonelli, "The changing role of pervasive middleware: From discovery and orchestration to recommendation and planning," in *PerWare Workshop at the 9th IEEE International Conference on Pervasive Computing and Communications, Seattle (WAS)*, March 2011, pp. 214–219.

[18] A. Rosi, M. Mamei, F. Zambonelli, S. Dobson, G. Stevenson, and J. Ye, "Social sensors and pervasive services: Approaches and perspectives," in *PerCol Workshop at the 9th IEEE International Conference on Pervasive Computing and Communications, Seattle (WA)*, March 2011, pp. 525–530.