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Agent and multi-agent applications to support distributed communities of practice: a short review

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Abstract This paper concerns the relationship between agents or multi-agent systems and distributed communities of practice. It presents a review of a number of agent and multi-agent applications with features that could contribute to supporting distributed communities of practice. The association is promising because of features like autonomy, pro-activity, flexibility or ability to integrate systems that characterize agents and multi-agent systems. Furthermore, such an association is a step towards building mixed communities of humans and artificial agents. To understand how agents and multi-agent systems could answer some of the needs of distributed communities of practice, we organize the analyzed applications into five different categories defined by considering the main activities of a community, namely: Individual Participation, Synchronous Interactions, Asynchronous Interactions, Publishing and Community Cultivation. Such a classification helps us identify the relevant features of the current technology and determine some that should be further developed, e.g. to support community coordination or gather information related to virtual communities. For each application we selected, we present its main approach and point out its potential interest.

Keywords Multi-agent system · Intelligent agent · Community of practice · Applications for virtual communities

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1 Introduction

The notion of community of practice (CoP) has been used in different domains, like social sciences, education or knowledge management, to study and understand learning and collaborative work [6,13,23,33,37,46,47,54,84,97,119].

The proliferation of CoPs and the widely spread use of Internet tools, ranging from email to virtual environments, led to the creation of distributed CoPs (DCoPs). DCoP members face more difficulties to perform their communal activities than members of co-located CoPs. Such difficulties are due to distance among members (who cannot rely on face-to-face interactions), lack of awareness concerning other members' activities, high number of members, or different cultural mindsets [119]. Clearly in this context, systems able to support DCoP activities are highly desirable.

We argue that, since its beginning, the research in multi-agent systems was associated with notions of social science. From such a premise, we built our argument to justify the association between multi-agent and agent technologies with distributed communities of practice. From the technical point of view, agent and multi-agent technologies possess characteristics such as autonomy, pro-activity, flexibility and ability to integrate systems, making them eligible as support systems. Furthermore, in the long term, such systems will lead to communities that mingle humans and artificial agents.

Given the potential of the association of MAS and DCoP, we decided to look at the state-of-the-art of agent and multi-agent systems from the perspective of supporting DCoPs. Therefore, to classify the systems and to structure our study, we used the categorization proposed by Wenger et al. [120] that considers five types of activities performed by members of DCoPs: Synchronous Interactions, Asynchronous Interactions, Publishing, Community Cultivation and Individual Participation. Thus, we could identify which DCoP activities are supported by current agent and multi-agent systems, and envisage some features and characteristics to improve such a support.

In the paper we first define distributed communities of practice, mentioning some of their particular features. We then present agents and multi-agent systems (MAS) discussing arguments that justify their interest for supporting a community. We then explain how we conducted the review and present the analysis and categorization of the selected systems. We end up with some comments and conclusions on the work.

2 Communities of practice

In this section, we discuss the notion of communities of practice and some related concepts such as identity, trajectory, and multi-membership. Such concepts help justify the use of agents and multi-agent systems as tools to support DCoPs and to understand the potential usefulness of the systems reviewed in the present paper.

2.1 An evolving notion

The notion of community of practice (CoP) was proposed by Lave and Wenger [58] in their seminal work "Situated Learning: Legitimate Peripheral Participation". Since then, it has evolved. Cox [23] and Kimble [54] agree that its evolution underwent three periods, each period being associated with a major work. The first period is characterized by the work of Lave and Wenger. The second period is defined by the book "Communities of Practice: Learning, Meaning and Identity" by Wenger [118]. The third period can be associated with the book "Cultivating Communities of Practice: a Guide to Managing Knowledge" by Wenger et al. [119].

Cox [23] and Kimble [54] agree that the changes in the notion of communities of practice were considerable. In the first period, Lave and Wenger [58] focus on the concepts of Situated Learning and Legitimate Peripheral Participation, and leave the notion of CoP intuitive. They consider that a CoP is a set of relations between people, activities and the world. For them, a CoP is an intrinsic condition for the existence of knowledge not only because it provides a background to interpret information, but also because the social practice defines what is possible to learn.

In the second period, Wenger [118] puts the notion of CoPs in the center stage, developing it and its relations with other concepts like identity, meaning and learning. He does not provide a straightforward definition for CoP, but characterizes it by describing three aspects of the relation between community and social practice: mutual engagement, common enterprise and shared enterprise. The mutual engagement brings a sense of belonging to CoP members. Belonging to a CoP means engaging in its practice. The mutual engagement is built and maintained by shared informal activities. A common enterprise gives coherence to the CoP. Such coherence is created and kept by the continuous negotiation of the common enterprise. The common enterprise creates mutual accountability between members helping them define what is relevant and acceptable. In the pursuit of the common enterprise, CoP members elaborate several resources that form a shared repertoire. Such a repertoire includes routines, words, tools, procedures, etc.

The third period is more prescriptive. Wenger et al. [119] develop recommendations on how to apply CoPs to Knowledge Management initiatives. In this period, Wenger et al. define a CoP as "a group of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in the corresponding area by interacting on an ongoing basis." They also present a structural model of CoP that includes three elements: (i) a domain of knowledge; (ii) a community of people; and (iii) a shared practice. The domain defines a set of issues and legitimizes the community by asserting its purpose and value to its members. The CoP's domain motivates its members to participate and contribute. Such a domain also helps members define what activities should be performed. The community creates the social fabric of learning and fosters interactions and relationships based on mutual respect and trust. This kind of relationship creates an environment encouraging people to share ideas, to expose their ignorance, to ask questions and to listen carefully. The practice is a "set of frameworks, ideas, tools, information, styles, languages, stories and documents that community members share." It represents the knowledge that the community creates, shares and maintains [119].

It is possible to observe that in the first period, the notion of CoP is more abstract and open than in the subsequent periods, making it more difficult to be applied in the analysis of tools to support distributed communities of practice (DCoPs). Despite the absence of a definition of CoP, the second period provides a theoretical framework with concepts, such as identity, that are more appropriate to analyze tools able to support DCoPs. The approach of the third period is not as deep and complex as the previous ones but contains some concepts, such as a structural model of a CoP, which can be useful in the analysis of tools able to support DCoPs.

2.2 Distributed communities of practice

Although suggested in the second period when the notion of locality is discussed, distributed communities of practice are defined in the third period. A DCoP is a CoP in which members are distributed geographically and thus, cannot count on frequent face-to-face (formal or informal) meetings to interact. Since DCoP members do not work close to one another, they use technological means like videoconferencing, email or virtual environments to interact [119]. DCoPs can bring together people spread in different units of an organization or even in different organizations.

DCoPs must overcome a set of obstacles to succeed. The most obvious is the distance. A DCoP is less "present" in the members' routines. A community makes itself "present" when members run into one another at the cafeteria, or in the hall, or when they hold a face-to-face meeting. In a local community it is easier to connect informally with other members, and members are more visible. Even if a member does not expose his opinion in a meeting, other members can observe his passive participation. Newcomers can speak in private when they run into another member in the cafeteria to network informally. In a DCoP, it is difficult to observe who is participating passively by just reading the messages on the discussion board. It is also difficult to meet other members fortuitously or to connect informally during teleconferences.

DCoPs have more potential members than local ones, so they tend to be larger, making it difficult to know everybody personally and to establish relationships based on trust and mutual respect. The number of members can also impact the community structure. For example, a large distributed community can be divided into sub-communities with local coordination.

DCoPs can also face cultural issues. As they can have members distributed all over the world, distinct national cultures can affect the way a community works considerably. For example, in some cultures, newcomers can feel extremely uncomfortable to criticize or even ask questions to senior members. Language is also an important factor. For example, members that are not proficient in the DCoP "official" language can find it difficult to express their viewpoints clearly. All these peculiarities make the development of DCoPs more difficult [12,61,100,119]. Considering such characteristics, tools able to support the development of such communities are desirable.

2.3 Identity, trajectories and multi-membership

The notions of identity and trajectories were introduced in the first period, but they were only fully developed in the second one.

The notion of CoP belongs to a wider theoretical framework, described in the first period, as Situated Learning. A CoP is the place where the process of Legitimate Peripheral Participation takes place. In this process newcomers build an identity in the process of becoming old-timers. Newcomers start from a peripheral participation to achieve a full participation [58]. In this context, the concept of identity plays a major role, because the development of an identity implies learning the CoP practice.

In the second period, Wenger [118] argues that newcomers feel more acquainted with some communities than others and when joining some of them, they continue forging their identity. A newcomer will learn the community practices, will become more proficient in its domain and will share knowledge as a way to belong to this community. Belonging to a community helps building an identity because it helps defining what is to be known and what can be ignored.

Identities are not static, they change in time. They have trajectories inside communities that represent the past, the present and the future of the community members. The analysis of emblematic trajectories could help newcomers envision their future and allow old-timers to revisit their own history.

Identities also develop through space, they cross boundaries among communities. People participate in several communities and they can neither use a specific identity for each of them nor use the same identity in each of them. Each person develops different aspects of the same identity in order to participate in different communities. Multi-membership is an inherent aspect of identities being a bridge between different communities and constituting another way to expand identities [118].

2.4 Life cycle

The notion of CoP life cycle is developed in the third period. Wenger et al. [119] argue that a CoP has a life cycle. Such a cycle has five stages: potential, coalescing, maturing, stewardship and transformation. In the potential stage, possible members are loosely connected. As such members start to build connections, they coalesce into a CoP. In the maturation stage, more members join the CoP and the knowledge sharing between members is deeper. In the stewardship stage, CoP members develop their knowledge and practices consciously. In the transformation stage, CoPs can: disappear, split into sub-communities, become a different type of group (e.g. a department) or merge with other communities.

3 Agents and multi-agent systems

In this section, we briefly discuss agents and multi-agent systems. We seek to justify the use of Agent and MAS technology to develop systems able to support DCoPs.

3.1 Agents

Wooldridge [121] considers that "the notion of an agent as an isolated system is evident in early AI (artificial intelligence) literature." However, not until the 1980s, would agents constitute a central concern for the AI research community [50]. Even if agents have been considered a research subject since then, there is not a consensual definition of agent [7,18,25,50,114].

Most AI researchers accept the two different types of agency defined by Wooldridge and Jennings [114,122]: weak and strong. A "weak" agent has the following properties: autonomy, social ability, reactivity and pro-activity. A "strong" agent has the same properties, but is conceptualized or implemented using notions that would be usually applied to humans such as: beliefs, intentions or knowledge [122].

In a later work, Jennings et al. [50] adapt a definition from Wooldridge and Jennings [122]: "an agent is a computer system, situated in some environment [...] capable of flexible autonomous action in order to meet its design objectives." In such a definition, three concepts are emphasized: situatedness, autonomy and flexibility. Situatedness refers to the agent's ability to receive data from the environment and act to change such an environment. Autonomy is the capacity of acting without the direct intervention of humans and controlling its internal state and actions. To be flexible, agents should be: responsive, pro-active and social. An agent is responsive if it can respond to changes in its environment in a timely fashion. To be pro-active, an agent should present a goal-directed behavior and initiative when appropriate. An agent is social if it is able to interact with other artificial agents and humans in order to achieve its goals and help other agents [50]. Capacities such as the ones mentioned above would be useful in systems able to support DCoPs.

Case et al. [17] do not refer specifically to DCoPs, but argue that intelligent agents can provide an appropriate platform to provide support for electronic communities. As DCoPs, electronic communities connect geographically dispersed people. Case et al. consider that an intelligent agent should possess some or all of the following capacities: cooperation, pro-activity and adaptability. For example, an agent with adaptive behavior could retrieve more personalized information using its user's previous information searches. Pro-active agents could execute the search for a piece of information without user intervention. Although different from the one used by Jennings et al. [50], the set of characteristics that define an intelligent agent for Case et al. looks similar. Notions like pro-activity and sociability are present in both sets.

We consider that even "weak" agents or stand-alone agents could be useful to support the activities of DCoP members because they possess capabilities like autonomy and pro-activity. Such capabilities make them interesting to provide services such as personalized information retrieval and collaborative filtering. Since the DCoP members' activities are performed in parallel with other activities like those of a project team, members do not have much time to devote to community tasks. Agents that are autonomous and pro-active can help them decrease their workload by performing tasks that can be automated such as information retrieval.

However, although useful when supporting DCoPs, "weak" agents and stand-alone agents can only offer a limited support. For example, different agents could require different user profiles to work efficiently. They could also require different interfaces to interact with their users. To minimize the effects of such limitations, multi-agent systems could be deployed.

3.2 Multi-agent systems

Despite the gap between researchers in academia and industrial users, Multi-agent systems (MAS) have been deployed in several domains [79,80] such as concurrent engineering [91], manufacturing [78–80,91], knowledge management [108], communications [68], air traffic control/flow [2,80], logistics [80], space exploration [80,92], or e-commerce [86,93].

They can be used to intelligently assist users in specialized or generic tasks. Specialized tasks include, among others, network management [68] or operation of CAE tools [73]. Generic tasks include handling information (e.g. retrieving, filtering, synthesizing), making decisions (decision support systems) [55] or capturing lessons learned by a project team [108].

Based on the work of Durfee and Lesser [27], Jennings et al. [50] and Sycara [105] define a MAS "as a loosely coupled network of problem solvers that interact to solve problems that are beyond the individual capabilities or knowledge of each problem solver." The problem solver mentioned in the definition is an agent. Sycara [105] also describes the abilities presented by multi-agent systems that make them an interesting research subject. Such abilities can also be used to argue that multi-agent technology is a promising technology to implement systems able to support DCoPs.

The first ability is the capacity of solving problems that are so large that a centralized agent would not have enough resources to do so. Furthermore, a centralized agent would become a performance bottleneck or a source of risk because of the possibility of failure at critical times. In the case of systems supporting DCoPs, it is difficult to estimate whether or not the problem is large enough to justify the use of a MAS. DCoPs tend to be larger than the local CoPs, but they can remain small. Wenger et al. [119] mention a large community with about 1.500 geographically distributed members at Shell. Such a community shares resources with other communities, so there are potentially more people using the same systems to interact. We consider that, although relevant, the capacity of solving large problems is not a decisive argument to select MAS as a technology to implement systems to support DCoPs.

The second ability is making possible the interconnection and interoperation of multiple legacy systems. The idea is to use an agent wrapper around each system and incorporate them into a group of agents. It is then possible to make the features of the legacy systems available to the new systems. An example of the integration of legacy systems is the integration of agents developed by different groups to simulate the evacuation of civilians from threatened locations. Such integration was developed in the Teamcore framework, a framework for building agent organizations [82,112]. Such ability can be very useful for systems able to support DCoPs. Not just because systems that possess such an ability can incorporate legacy systems, but because, by using a similar approach, it is possible to incorporate new features to the current system. As DCoPs have life cycles, it is probable that they would use different tools to perform their activities as they evolve. For example, a DCoP could start with a small group of people, with no specific funding, that tends to choose among the available tools (e.g. freeware). As the DCoP grows, either different types of features might become desirable, or the DCoP might become "official" in an organization and be obliged to "transfer" its activities to an "official" system. In either case, the ability to interconnect and to allow interoperation could be useful. If new features are required, an agent wrapper could be used to incorporate it to the current system. In the second case, an agent wrapper could be used to incorporate the old system to the "official" one.

The third ability is to solve problems "that can naturally be regarded as a society of autonomous interacting components-agents" [105]. We consider that supporting DCoPs is a problem that fits such a description. Although Hattori et al. [44] do not refer to DCoPs specifically; they argue that a MAS is an attractive technology to support networked communities. The distributed character of this type of community fits in a distributed architecture like the multi-agent architecture.

The fourth ability is the capacity of using distributed information sources to solve problems. As the members of a DCoP are geographically distributed, so are the information sources. Even if central repositories of information are used, members themselves can also be considered as sources of information and they are geographically dispersed. Furthermore, DCoPs develop their activities over the Internet, considered the ultimate distributed information source.

The fifth ability is solving problems using distributed expertise. In the case of DCoPs, the fifth ability is similar to the fourth. Old-time members could also be geographically distributed.

The sixth ability is the capacity of improving the performance along the dimensions of computational efficiency, reliability, extensibility, robustness, maintainability, responsiveness, flexibility, and reuse. From the above, we consider that the flexibility and the extensibility are likely to be the basis for developing applications that better meet the evolving needs of a community. CoPs can differ from one another [119]. For example, some communities can prefer the use of asynchronous tools like email or blogs, while others will prefer using synchronous tools like chats. Furthermore, DCoPs have life cycles. In this context the tools used in the community must also change. In this case, the flexibility and extensibility inherent to a MAS can help provide an always adequate set of tools for the community. Hattori et al. [44] do not refer to CoPs specifically, but they argue that the support system for a virtual community should handle the dynamic nature of such a community whose members change the way they participate in the community.

Thus, analyzing the abilities described by Sycara [105] regarding the characteristics of DCoPs, it is possible to consider multi-agent technology as a promising technology to develop systems for supporting DCoPs.

Furthermore, virtual communities have other issues that can be handled by a MAS. Hattori et al. [44] argue that the use of personal agents can preserve the individuality of each community member. Community members share some objectives, but they also have individual objectives. As community members have different interests, they can participate in different communities. The inclusion of personal agents in MAS can personalize the support to the specific needs of the individual and preserve the individuality of members. The personal agents can also be used to alleviate the workload of community members by unifying the interface to several systems. Since DCoPs share the same issues, we consider that the authors' arguments can also be applied to DCoPs.

It is also possible to identify some advantages provided by multi-agent technology when comparing approaches using a MAS to others using different technologies. Hattori et al. [44] argue that, as virtual community members are dispersed and the number of potential members is large (as DCoPs), solid, centralized and monolithic solutions would not be an adequate solution. Such types of solutions include most groupware and portals.

Barthès and Tacla [5] identify advantages and limitations of using a MAS or a groupware-based portal to manage knowledge. The groupware is a more mature technology, but has limited pro-activity and extensibility. In contrast, most limitations of the MAS approach are related to the fact that it is not as mature as groupware ones. Thus, Barthès and Tacla propose a combination of both approaches by using an agent to encapsulate some of the groupware features. By combining agents and groupware, they try to overcome the limited pro-activity and extensibility of groupware systems. They compare the performance of groupware and MAS to manage knowledge, leading us to consider that their analysis might also be applied to systems that support the activities developed by DCoPs. The portal described by Barthès and Tacla has features similar to the ones found in systems supporting DCoPs such as document repositories, directories, and calendars.

The research in Computer Supported Cooperative Work (CSCW) and groupware has several points in common with the research in DCoPs. Both domains have a multidisciplinary character (about such a character in CSCW [28,42] and in CoPs/DCoPs [118]) and are concerned about facilitating human to human interaction by means of technological tools. Several systems we surveyed for our review are groupware tools (e.g. [41,126]). The points in common between the two domains make them overlapping domains.

Despite the existence of common characteristics, it is possible to identify distinctions between both domains. Ellis et al. [28] mention in their definition of groupware "a group of people with a common goal or task." DCoP members could have common goals or tasks, but usually they join DCoPs to learn by participating in the communal activities [118]. In DCoPs, goals can be loosely defined or implicit and a specific task (e.g. elaboration of a manual about the community domain) could be carried out by a small part of the community members. Boundaries of groups using groupware tend to be clear and DCoPs tend to have fuzzy boundaries (e.g. lurkers are relevant participants in a DCoP) [119]. Usually groups using groupware and DCoPs should be managed in different ways. In DCoPs, the attribution of roles is not so rigid and the management should be "light handed" [119]. Schedules and deadlines are not central in DCoPs' activities. In the other hand, groups using groupware usually have to control schedules, respect deadlines and their members should play their roles in order to achieve the group's goals.

The CSCW/groupware domain and the CoPs/DCoPs domain have similarities and differences. We think the cross fertilization of both domains can bear valuable fruits. CoPs and DCoPs can benefit from a well established research tradition and CSCW/groupware can benefit from a new social perspective.

The emergence of the semantic web [9] also creates an opportunity to combine technologies. Pechoucek and Marík [80] consider that the semantic web and service-oriented architectures affect considerably the way agent technology will be developed and applied in the future. Chen et al. [21] combine intelligent agents and Web Services to develop an automated meeting room. The work presented by Chen et al. suggests that it is possible to integrate, through a MAS, features from legacy systems, intelligent agents and web services to provide a system to support DCoPs.

We consider that the discussion above strongly suggests that MAS technology is appropriate to implement systems able to support the activities developed by DCoPs. We think that a major argument in favor of the association of multi-agent systems and DCoPs has not yet been explored in this paper. Such an argument involves a vision of how people and artificial agents would interact in the future.

3.3 Communities mixing humans and artificial agents

It is possible to argue in favor of the association between multi-agent systems and DCoPs at a higher level. Research works in both domains are concerned by the social nature of action and knowledge. The framework in which the notion of communities of practice is developed considers that learning is an integral part of the social practice. The MAS research can inspire and be inspired by social studies.

A foundational aspect of the MAS research should be its concern with the "social dimensions of the action and knowledge as a fundamental category of analysis" [32]. Malsch [66] and Malsch and Schulz-Schaeffer [67] materialized such a concern in a research field called Socionics. It is possible to identify three main interests in this research field: (i) the social investigation by means of simulation of social groups and societies; (ii) the investigation of the social metaphors used in the development of multi-agent systems; and (iii) the investigation of the effects of societies mingling human and non-human agents in the human being.

Simulation can be used to study groups and societies because it allows researchers to change social parameters and analyze the effect of such a change. Fan and Yen [31] survey works such as COGNET/BATON and Team-Soar that use agents to simulate teamwork. The former can simulate different kinds of collaboration, the latter was used to test a theory of team decision making. McCallum et al. [70] use simulation to analyze the effect of the influence in organizational change. Zoethout et al. [133] examine, by means of simulation, how a workgroup modifies task allocation when facing different kinds of task. Glass and Grosz [36] analyze how social consciousness affects the negotiation process during decision making and the outcomes of the teamwork.

Social metaphors are used in the development of multi-agent systems. Metaphors such as agent societies, agent organizations and agent ecologies are used in the domain of agent-oriented software development [131]. In the extended version of the Gaia methodology [132], the MAS architecture is defined in terms of organizational structure. A role model is used to organize agents in hierarchies, collectives of peers, market-oriented structures, etc. Van Aart et al. [116] use notions from the domain of organization design to develop a MAS. They discuss three MAS architectures that are based in the Mintzberg's organizational structures: machine bureaucracy, professional bureaucracy and adhocracy.

We have concentrated our discussion of societies mingling human and non-human agents to the discussion of communities mingling humans and artificial agents. Although farfetched in the current technological context, it is possible to envision a world where humans and artificial agents would constitute communities in which artificial agents would behave almost as humans. Such a possibility seems to have inspired different research works that associate humans and artificial agents.

Barthès [4] proposes an environment called Multi-Agent System with Humans (MASH) to manage the knowledge of a project team. In the MASH environment, each team member owns a set of agents composed of a personal agent and an exclusive staff of agents. Each set of agents acquires on the fly the knowledge of its owner. The acquired knowledge can be exchanged among team members through their personal agents. If a member quits the team, his personal agent keeps contributing with the knowledge previously acquired.

Urlings et al. [115] use a video game called "Unreal Tournament" as a virtual world containing humans and agents (implemented with the JACK platform). In this virtual world, teams associating humans and agents are formed. The idea is to train users in combat situations using simulations.

Tambe et al. [112] use an agent integration architecture called Teamcore [82] to group humans and agents. In the Teamcore, each human or agent is associated to a proxy. The proxies can work as a team because each has a teamwork model that is used to coordinate its actions with other proxy actions. To demonstrate how the Teamcore works, the authors describe two applications: casualty rehearsal evacuation exercise in threatened areas and coordination of meetings.

Sierhuis et al. [92] describe the mobile agent project based on a research that involves the formation of teams mingling humans and artificial agents to be employed in space exploration. The idea of the project is to use a system to coordinate the action of the mobile agents and have them collaborate. Mobile agents are entities such as space suits, cameras, all-terrain vehicles, and robotic assistants. Each mobile agent and person involved in the current operation has a personal agent that is used to facilitate the communication between humans and mobile agents as well as between mobile agents.

Isbell et al. [48] developed an agent called Cobot that became a member of a community formed inside a virtual world. It has evolved from an inanimate object to a socially adaptive agent. Cobot is able to adapt by collecting statistical information about users' interactions. It can also present such information to other community members. Isbell et al. consider that Cobot became one of the most "popular" community members and it altered the interactions within the community.

The research works we just described promote the idea of creating communities mingling humans and artificial agents. The existence of the research suggests that the possibility of creating such communities is not negligible. Using a MAS to develop systems to support a DCoP cannot be characterized as an attempt to create communities mingling humans and agents, but we consider that the future of such systems involves the creation of this type of community. We think that the idea of associating multi-agent systems and DCoPs is justified not only because MAS technical characteristics are appropriate to support DCoPs, but also because the possibility of mingling humans and artificial agents suggests that such an association is a first step towards the development of new associations between humans and technological artifacts.

4 The review study

This review aims at mapping the agents and MAS applications that could support the activities of a DCoP. The idea is to identify which activities performed by DCoPs are already supported and the new features that are potentially useful for DCoPs. Such features can be appropriately explored through the use of agent and MAS approach.

When we started looking for agents and MAS applications oriented towards DCoPs, we found out that most of them are aimed at several types of virtual communities. That led us to consider them all and not just the ones explicitly dedicated to DCoPs. Although several applications do not meet all generic needs of DCoPs, they present useful features able to support such communities. We also decided to include both "weak" and "strong" agents.

To guarantee that this study could constitute a representative (but not exhaustive) landscape of agents and MAS applications for communities, we consulted three of the most relevant scientific/technical databases: Elsevier/Science Direct, IEEE/Computer Science and ACM/Digital Library. We decided to focus our study mostly on the papers published after 1999, eventually including some from previous years. We chose 1999 because the concept of CoPs started to spread after Wenger had published "Communities of Practice: Learning, Meaning and Identity" [118], despite the fact that the concept of "community of practice" had already been presented in "Situated Learning" in 1991 by Lave and Wenger [58].

In order to organize our findings, we classify the analyzed systems using the framework proposed by Wenger et al. [120]. The framework is used to analyze technologies that could be utilized to help community leaders and their sponsors select tools for supporting communities without over-emphasizing such tools. Although using the same classification scheme, in our review we do not intend to help leaders and sponsors choose the most appropriate tools for their communities.

The framework includes a diagram showing how tools utilized by communities fit in their activities. The diagram is divided into five regions corresponding to different types of community activity: Synchronous Interactions, Asynchronous Interactions, Publishing, Community Cultivation and Individual Participation. The location of the tools in the diagram is meant to show their intended use and relation to the other tools (Fig. 1).

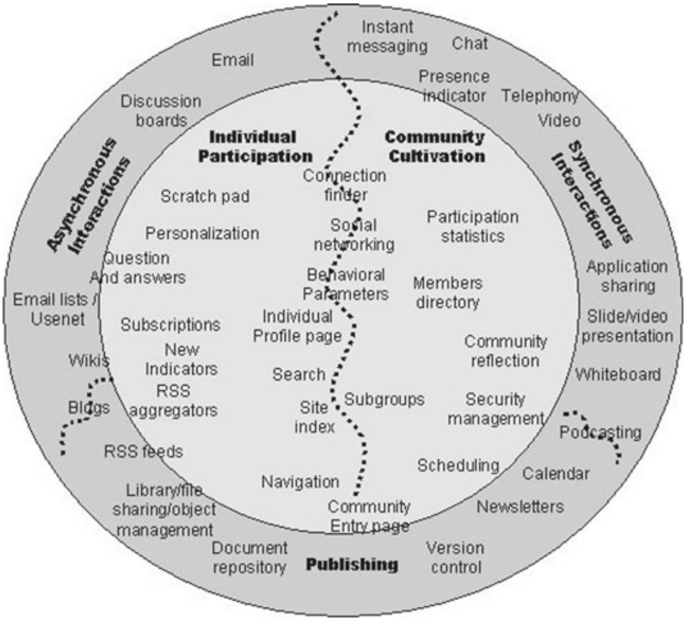

Fig. 1 Community tools [120]

In our review, we locate features of agent and multi-agent applications in the diagram elaborated by Wenger et al. [120] by considering their potential contribution to the execution of typical community activities. We also tried to make explicit the relation between applications. In doing so, we sought to establish a framework picture of how the current agents and multi-agent systems are inter-related. Such a picture could also be used to suggest which kind of tool is lacking. We first classified the applications into the five categories of the diagram (Synchronous Interactions, Asynchronous Interactions, Publishing, Community Cultivation and Individual Participation). Then, we grouped the studied agents and multi-agent systems by feature (whenever possible) and positioned each group in the diagram.

Some of the analyzed multi-agent systems and agents present features that could fit into more than one type of activity. In this case, we selected the features that seemed more important or predominant in the system for classifying it.

This classification, using the activities of communities, was adopted instead of a classification based on the system features, because the core intention of this review is to identify the state-of-the-art in multi-agent systems and agents for supporting communities, meaning that we do not intend to compare systems in a given domain (e.g. information retrieval), but to look for some insight on how such systems potentially support the activities of a community.

5 Survey of tools and systems

Again, the aim of this study is to survey how multi-agent systems and agents are used to support community activities and not to compare systems that support communities. The multi-agent systems and agents described in this section are not comparable for many reasons. They are at different stages of development, implemented with different technologies and for different purposes.

5.1 Individual participation

The tools for individual participation are chosen for their potential to support community members performing tasks for the community. They are not necessarily intended for communities, but can be useful for members performing some tasks in a community.

Basically, all the tools for supporting individual participation are intended to help users handle problems related to information or explicit knowledge. In order to provide an overview of the available tools, we classified them according to their major features. In the "Individual Participation" category, we identified five major features: Individual Profiling, Personalized Newspaper, Support to Web Navigation, FAQ Retrieval, and Information Filtering/Retrieval (Table 1).

5.1.1 Descriptions of the systems

One of the tasks that should be well supported in individual participation is the access and use of multiple distributed sources of information and explicit knowledge. Personalized assistance to improve users' performance in the execution of everyday tasks could also be useful. Both the access to information and the assistance should be as personalized as possible, thus personal profiles might be necessary.

Table 1 Major features identified in the Individual Participation category

Major feature	Agents and multi-agent systems
Individual Profiling	SUITOR [65]
Personalized Newspaper	WebMate [20]
	NewsAgent [38]
	ETTS [15]
Support to Web Navigation	[53]
	[96]
FAQ Retrieval	[123]
Information Filtering/Retrieval	AgentRAIDER [90]
	Watson [14]
	MAIS [29,30]
	MAPIS [81]
	[51]
	[98]
	[88]
	[95]
	Personal Search [37,38]
	Several examples [55]

Klusch [55] reviews agents that possess one or more of the three features: information acquisition and management, information synthesis and presentation and finally intelligent user assistance. Most of the agents in his review can be used to support the individual participation in communities. In his review several systems that could support individual activities are mentioned: SIMS/ARIADNE, MIX, ABS, TSIMMIS, OBSERVER, InfoSleuth II, BIG, PLEIADES, IMPACT, SCOPES, RETSINA [106], Amalthaea [74], InfoSpider [77], LikeMinds and FireFly. The review also mentions personal information agents deployed in Virtual Reality environments and other personal agents like: Letizia, Remembrance, ExpertFinder, Butterfly, Let's Browse [63], TrIAs, AiA, PAN, WebPersona and others.

An example of a system that could be used to build a user profile is an attentive information system developed over an architecture called Simple User Interest Tracker (SUITOR). Such a system can determine users' interests in order to provide useful information by following their behavior. It builds a user's model by tracking eye gaze, web browsing and application use [65]. Agents and multi-agent systems to build profiles could be used to provide better services to community members like handling the increase in the workload caused by the participation in DCoPs.

Agent for Retrieval and Analysis of Information in Distributed Environments (AgentRAIDER) interfaces the user to a system composed of commercially available components that implement a comprehensive architecture for an information retrieval system [90].

Watson is a system that proactively retrieves information from distributed information sources based on the context gathered from the document on which the user is currently working. One can also use Watson to perform explicit requests based on a reference document [14]. Instead of using a document to gather context, the system developed by Staab and Schnurr [98] can look for information related to the task that is currently being performed by the user. It retrieves information from an organizational memory, either in a reactive or in a proactive way.

MAIS [29,30] is a system that performs personalized searches on the web. To achieve this personalization, the system builds a user profile based on a set of centers of interest. Each center consists of documents representing the user's interests. To search a piece of information, the user provides some keywords and centers of interest to the system through a Personal Assistant. A Search Agent retrieves the pages identified by commercial search engines (e.g. Google, AltaVista) using the keywords. A Filter Agent orders the retrieved pages using the user's profile and a machine learning technique.

Multi-Agent Personalized Information System (MAPIS) interacts with users and the different information sources to provide personalized information. The agents in MAPIS play different roles. Assistant Agents interface users and the system, Search Agents search information in the available sources, Profile Agents manage the users' profile and Solver Agents coordinate the information retrieval, personalization and integration. The information personalization considers the information domain, the search request history and the users' profile [81].

SUITOR, AgentRAIDER, Watson, MAIS and MAPIS build users' profiles using contextual information like documents and tasks, but metadata can also be used to retrieve information. Ji and Slavendy [51] developed an agent-like metadata filter that retrieves information from an intranet portal that works as an organizational memory.

The cited systems favor automatic construction of users' profiles. Other systems favor interaction with users to build their profile. Still the goal is the same: to improve the retrieval of information in distributed sources. Shakshuki et al. [88] developed a system that builds the user's profile during interaction. The system uses the profile to customize retrieved information for the user. It can also monitor and update modifications in the information sources.

Song et al. [95] developed a system to filter and classify documents, by simply analyzing their titles. The system has two agents: a Classification Agent (CA) and a Filtering Agent (FA). The CA uses an information inference model that allows it to discover implicit information in the document titles. The information inference model deploys a model of semantic memory based on a significant corpus of texts. Using this mechanism, the CA can infer the context of the document from the words in its title. The inference model allows the CA to establish a set of categories that can include the analyzed document. The FA uses the user's profile to define which categories can interest the user.

Agent and multi-agent systems filtering and retrieving information as mentioned above, can be useful to DCoP members. As they use several types of techniques to build profiles, they can improve information retrieval allowing DCoP members to participate more effectively in the communal activities. We think that the filtering and retrieving systems described above could be more efficient if they would consider a community profile as the systems described in the publishing category section. As DCoP members can participate in different communities and have private interests, their profiles could present different aspects (e.g. one for each community). Filtering and retrieving systems would consider such aspects when personalizing retrieval. To do so, it is necessary to investigate how to "switch" between the different aspects of the profile or how to mix such aspects in order to obtain a better personalization.

Frequently Asked Questions (FAQ) systems are a considerable source of information. Yang [123] developed a Personal Assistant Agent that interfaces users and FAQ systems. The goal of such an agent is to provide the most adequate FAQ by "understanding" the users' intentions. To achieve this goal, the agent uses a domain-specific ontology, an adaptable user's model and techniques of linguistic treatment. It is a complex system that can potentially help integrate newcomers in communities. As newcomers usually need basic information about the domain and the practice of his new community, a tool to improve the access to FAQs is potentially useful to accelerate the integration of newcomers. We think that systems to retrieve FAQs could be useful, but they should be complemented with systems to extract FAQs automatically or semi-automatically from sources such as community forums or chats.

WebMate learns the users' interests continuously in different areas in order to provide an automatically generated personalized newspaper. The users' profiles are defined by the users' positive feedback when analyzing some documents. Moreover, using such dynamic profiles helps to refine search, improving the efficiency of the information retrieval [20].

Personal Searcher and News Agent are also agents that employ users' profiles to retrieve and organize information from the web. News Agent recommends articles from the user's preferred on-line newspapers. Personal Searcher searches the web for documents using keywords. Both agents use a user's profile elaborated from the observation of the user's behavior while navigating the web. The agents observe actions like the time spent at a page, the way the page is scrolled and the inclusion of bookmarks, to get an implicit feedback. The profile is also adapted and refined dynamically according to the feedback provided by the user about the suggestions given by the agents [37,38]. Personal Search was developed using the WebDCC algorithm for document conceptual clustering to model the users' preferences [38]. One of the advantages of these agents is the automatic construction of the profile from implicit feedback.

Emerging Topic Tracking System (ETTS) is a system that can monitor a region of the web, detect changes in the information about a specific topic and summarize them to the user. ETTS has three main components: Area View System, Web Spider and Changes Summarizer. The Area View System uses keywords provided by the user and commercial search engines to establish an "information region" that the system will monitor. Web Spider periodically checks the HTML files in this region to identify new pages and to detect changes in already checked pages. The Changes Summarizer extracts the changes from the documents (e.g. phrases included recently) and evaluates them using the Term Frequency-Proportional Document Frequency (TF-PDF) algorithm. The most relevant changes are the summary for the user [15]. Like the Web Mate and The News Agent, ETTS builds a customized newspaper, but it uses neither an implicit nor an explicit user's profile.

An agent or a MAS generating personalized newspapers or clippings are similar to systems to filter and retrieve information. We think that the main difference is their proactive character. Such a characteristic could help DCoP members to keep track of modifications in information sources regarding the community domain.

Keeble and Macredie [53] developed an adaptive interface to support web browsing. Their system can retrieve and cache linked web pages, suggest other web pages, organize bookmarks, perform background searches and repeat periodic page fetching.

Sorensen et al. [96] present an ensemble of agents that support web navigation based on the users' bookmarks and navigation history. Support is offered in the form of bookmark maintenance and automatic verification of updates in web sites.

Systems to improve web navigation could help DCoP members to find information in the World Wide Web more efficiently. They would be more useful if they could offer the same kind of services (e.g. bookmark maintenance, verification of updates, suggestion of web pages) for the community as a whole. Newcomers would benefit from such services and the DCoP could obtain an information source that can diminish the effect of old-timers' departures.

There are several approaches, methods and techniques for information filtering and retrieval from distributed and heterogeneous sources as well as for user profiling. This review is limited to the studies described above because we considered that they represent the kind of support agents can give to the individual participation in DCoPs.

5.1.2 Discussion

We observe that different approaches have been studied for the same problem. An example is the elaboration of profiles. Some systems try to follow users' behaviors in order to determine their preferences and others rely on users' feedback. Some systems can define the users' preferences in multiple areas. Several algorithms for information filtering and retrieving have also been studied. Such research efforts might lead to more appropriate tools for supporting individuals participating in communities. But, as they are not community oriented, they will possibly neglect specific needs of DCoPs.

The notion of identity in the DCoPs theoretical framework is rather complex, thus it cannot be reduced to a personal profile, a user's model or a set of preferences. However, we can consider that profiles, models and preferences are "glances" of the community members' identities. They have been used successfully to personalize services in several systems, but we consider that it is possible to improve them considering other dimensions of the notion of identity.

In the DCoPs theoretical framework, since a person belongs to several communities, one develops different aspects of the same identity. For each community the person belongs to, one of these aspects is more significant. We think that a profile or a user model should consider the multiple aspects of an identity. Some of the systems described in the previous section, like MAIS, deal with the user's many interests, but it is necessary to make the "current" interest explicit. Other systems, like Watson, use the current context (e.g. the document the user is working on) to determine the "current" interest.

The concern that an identity presents multiple aspects has been studied and considered in the profiles and user models. However, we argue that the multiple aspects of an identity have been treated in isolation. We consider that a person's identity is a whole; therefore the use of the different aspects in isolation does not ideally reflect the notion of identity. But to consider different aspects of an identity simultaneously implies estimating how much each aspect is affecting the execution of an activity at a given moment. In such circumstances, it is possible to envision a MAS in which each agent would represent one aspect of an identity and would negotiate its importance in a given context.

As identities change in time and describe trajectories inside and through DCoPs, we believe that the temporal dimension should also be considered. To our knowledge, such a dimension has been neglected in the profile and user models. Taking into account the temporal dimension exposes some issues. For example, how to evaluate the weight of the past experiences in a profile? What is the rate of update of a profile? When to "forget" something? If an identity composed of multiple aspects is considered, would the time affect each aspect differently?

It is possible to observe that, considering notions such as identity, trajectory and multi-membership; a set of issues regarding the development of agents and multi-agent systems to support DCoPs arises. Such issues suggest new subjects to be investigated.

5.2 Synchronous interactions

An agent or a MAS in this category can potentially support synchronous interactions in a DCoP. Synchronous interactions can happen in face-to-face meetings, videoconferences, teleconferences, chats or instant messaging. So, we classified the agents related to this kind of event in this category.

In order to provide an overview of the available tools, we classified them according to their major features. In the Synchronous Interactions category, we identified five major

Table 2 Major features identified in the Synchronous Interactions category

Major feature	Systems
Presence Indicator	Gleams of People [127]
Conversational Agent for IM	AINI [39]
Meeting Scheduling	[22]
	[59,60]
	RESCH [62]
	MSRAC [8]
	[89]
Spontaneous Synchronous Encounters	Contact Space/Forum [83]
	Freewalk [49,75,76]
Smart Meeting Rooms	Smart Conference Room [45]
	EasyMeeting [21]
	MITRE ETR [43]

features: Presence Indicator, Conversational Agent for IM, Meeting Scheduling, Spontaneous Synchronous Encounters and Smart Meeting Rooms (Table 2).

5.2.1 Descriptions of the systems

A typical system supporting synchronous interactions is a meeting scheduler. As negotiation is concerned, meeting scheduling is a well explored research topic in the MAS domain (e.g. [24]). Several systems implement different approaches [22,59]. Although meeting schedulers were not conceived to support DCoPs, they can help such communities be more efficient.

The RESCH project consists of a MAS to support collaborative work among persons in a company. In this project, one of the systems helps organize meetings. Each user has an assistant agent and an agent responsible for managing one's agenda. There is also a resource agent. The user assistant promotes meetings (that can be of different types) and negotiates with other user assistants. It can perform this task considering different factors like the kind of meeting and the hierarchical position of the participants. The agenda agent controls the availability of its user and the resource agent controls the availability of the shared resources like meeting rooms and slide projectors [62].

Lee and Pan [59] propose a system that helps schedule meetings using fuzzy decision agents. The advantage of such a system is to learn users' preferences and invitees' behavior. Lee et al. [60] refine Lee and Pan's system by using ontologies. Another system for scheduling meetings is proposed by Chun et al. [22]. The system is able to define participants' preferences by observing the negotiation involved in the meeting organization.

Meeting Scheduling with Reinforcement of Arc Consistency (MSRAC) is also a meeting scheduling system. The system is more compatible with the needs of actual organizations because it can relax users' preferences while keeping the overall consistency. MSRAC is extensible and experiments demonstrate its efficiency in handling situations with tight constraints [8].

Shakshuki et al. [89] also developed a meeting scheduling system. In such a system, users are represented by a Meeting Scheduling Agent (MSA) that negotiates meeting schedules with others MSAs. MSAs interact with their users through a GUI and with other MSAs though email messages or direct communication. To solve a conflict, the system proposes three negotiation strategies (First Come First Served, High Rank and Voting) based on the users' preferences and scheduling constraints.

Another kind of system that can facilitate synchronous interactions is the Smart Meeting Room systems. Hellenschimidt and Kirste [46] implemented a smart conference room using an infrastructure called SodaPop. The smart conference room is able to get a presentation from a notebook and to control lights, microphones, and loudspeakers.

EasyMeeting is also a smart meeting room system. It has been developed over an architecture supporting context-aware agents called Context Broker Architecture (CoBrA). Such an architecture includes context ontologies, context reasoning and control of the users' contextual information. EasyMeeting is able to recognize some vocal commands, to get a presentation from a specified URL, to play ambient music, to greet the meeting participants and display a specified web site. The aim of using the context is to allow the system to decide which services and information should be provided [21].

MITRE Experimental Team Room (ETR) possesses features that are similar to the features presented by EasyMeeting. The system can understand vocal commands; control the lights, the volume of the loudspeakers and the angle of cameras; turn on LCD displays and start a videoconference connection and navigate a slide presentation. The major feature is an embodied conversational agent called Electronic MITRE Meeting Assistant (EMMA) that is used as an interface between the user and the system [43].

Meeting Scheduling and Smart Meeting Room systems are designed to support face-to-face events. As DCoPs usually organize more on-line events, such systems tend to contribute peripherally to the support of DCoPs. They would be more useful if they would facilitate the organization of on-line synchronous events.

Meeting Scheduling systems and Smart Meeting Room systems are more adequate to facilitate the realization of formal events. To facilitate informal and casual meetings inside a community, there are more appropriate systems such as Forum and Freewalk.

The Forum system [83] was specifically designed for communities of practice. This web-based collaborative virtual environment deploys agents to support chance meetings, informal communication and information sharing among community members. The system has three components: (i) Contact Space; (ii) Meeting Space; and (iii) Jasper II. Jasper II agents can build user profiles by observing users' behaviors and information sharing preferences. The system can extract information from several sources accessed by users in order to build their profiles. It can also share information with other people whose profiles indicate similar interests. Contact Space can move users' avatars in a collaborative virtual environment in order to promote informal meetings while Meeting Space supports more formal meetings. Contact Space utilizes a profile for each interest group to place someone's avatar in an area where there are avatars of people with similar profiles. With Jasper II, Contact Space forms an intelligent environment for information sharing that facilitates information sharing within a community that is essential for the development of DCoPs. But it is necessary to include some more cultural and contextual information to allow people to get in touch through the system more easily [71].

FreeWalk 1 was also developed to promote spontaneous synchronous meetings. Freewalk 1 is part of the social interaction platform called Freewalk that also includes an agent to facilitate cross-cultural communication (Freewalk 2) and an environment to a virtual simulator for conducting virtual evacuation drills (Freewalk 3). But unlike Contact Space, Freewalk 1 allows people to move in a virtual space and to meet other people. Instead of avatars, Freewalk uses 3D polygons associated with video communication. Freewalk 2 is an agent to support human-to-human interaction. It animates a conversation and helps finding a common ground between two persons [49,75,76]. Both tools, FreeWalk 1 and 2, are not community oriented, but they can provide a virtual environment that could help finding people with common interests to form communities. Moreover, a DCoP can use this tool to minimize the lack of informal meetings.

Contact Space/Forum and Freewalk provide a virtual space that facilitates the occurrence of informal, spontaneous encounters. Such a space is important to DCoPs, because it can mimic the socializing effect of “hallway”, “cafeteria” or “water fountain” encounters. For example, newcomers can feel more comfortable asking questions to an old-timer in informal encounters. We think that one limitation of systems like Contact Space/Forum and Freewalk is their relatively closeness. They can promote encounters between people that are “wandering” in the virtual space created by the system, but not in open spaces like the Internet. Personal Assistant Agents could be used to indicate when a DCoP member is on-line in a chat room or navigating in a specific web site.

Another type of tool that can support synchronous interactions among CoP members is Presence Indicator systems, such as Gleams of People. Gleams of People is a system that allows users to share presence and humor indicators with other community members. When a community member chooses a color to represent his humor, the system sends messages to other members’ Personal Assistant agents to indicate his presence and humor. Each Personal Assistant responds, sending its user’s presence and humor indicators [127].

Gleams of People can be useful to reinforce the presence of members of distributed communities. It can be used to prompt spontaneous encounters. Presence indicators are current in several Internet systems such as Gmail, but they are usually restricted to a single system. We think that there is a lack of more general tools to indicate presence. Such tools should unify the interface to all Internet systems that require information about presence and status. Personal Assistant Agents could be an option to implement such a tool.

The instant messaging (IM) is a popular tool to interact synchronously. Goh et al. [39] developed a conversational agent, called Artificial Intelligence Natural language Identity (AINI), for this type of system. AINI uses two knowledge sources: a general and a specific. The system uses the Mindpixel (the training data of the Text Retrieval Conference—TREC) as a general knowledge source and ALICE Annotated AIML (AAA). As a specific knowledge source, it uses the knowledge extracted from web sites by Automated Knowledge Extraction Agent (AKEA). A conversational agent such as AINI could be useful to animate chat sessions. It could be also used to help integrate newcomers by providing basic information about the DCoP domain and practice.

5.2.2 Discussion

Although the agent systems for scheduling meetings, setting up and controlling meeting rooms can be useful for DCoPs, their contribution seems to be still peripheral and oriented to co-located CoPs. Tools like Contact Space, Freewalk and Gleams of People can play a more relevant role because they can help form and develop communities. Such systems can minimize the lack of informal meetings and can help members feel the presence of the community. Moreover, as they allow people with similar interests to get in touch informally, new communities can emerge.

Because DCoPs hold few face-to-face meetings, systems for scheduling meetings and controlling meeting rooms tend to play a secondary role in the support of such communities. However, since DCoPs meet in virtual environments, a system for scheduling meetings could be useful to schedule chats, videoconferences or conference calls. Occasionally, DCoPs promote face-to-face meetings. In such occasions, systems for controlling meeting rooms could be more useful if they keep a community profile. In this way they could configure the room

Table 3 Major features identified in the Asynchronous Interactions category

Major feature	Agents and multi-agent systems
E-mail Intelligent Forward	D-mail [64]
Forum of Avatars	TelMeA [110,111]
Analysis of Discussion Boards	CommunityBoard [44]
Virtualized Ego Interaction	EgoChat [57]

for the specific needs of a given DCoP. Systems for controlling meeting rooms would be more interesting to support DCoPs if they could configure the virtual environment in which a meeting or a videoconference is going to be held.

DCoPs would benefit from systems scheduling and supporting face-to-face events if such systems could perform similar tasks in virtual environments. Moreover, DCoPs could be better supported if such systems could keep a profile of the community.

5.3 Asynchronous interactions

Asynchronous interactions in DCoPs usually occur through emails, discussion boards, wikis and blogs. So, in this category, we include agents and multi-agent systems that can help users use such tools more efficiently.

In order to provide an overview of the available tools, we classified them according to their major features. In the Asynchronous Interactions category, we identified four major features: E-mail Intelligent Forward, Forum of Avatars, Analysis of Discussion Boards and Virtualized Ego Interaction (Table 3).

5.3.1 Descriptions of the systems

The Discovery E-mail (D-mail) system can send an email to the “appropriate” recipients by analyzing their web pages. The system analyzes the similarity between the email topic and the profile of the possible recipients. Such profiles are defined by an agent that analyzes the possible recipients’ web pages [64]. Such a system could be used in different ways for supporting communities. One possibility is the identification of potential members when a community is being formed. Another possibility is identification of sub-communities inside a large community. One limitation of the D-mail system is the profile used to define who should receive the email.

EgoChat was developed to allow the sharing of community tacit knowledge through narratives. Each member of the community is represented by a virtualized-ego (VE) that interacts with other members’ VEs. A member accesses community tacit knowledge by interacting with VEs and observing the exchange of messages among them. VEs exchange messages with voices and gestures. A structured list is used to describe personal tacit knowledge [57]. Newcomers in a community could use this system to learn about the community domain, accelerating their process of integration. The system can also help newcomers feel more comfortable interacting with their VE before posting questions to the community discussion board.

TelMeA is an asynchronous communication system for communities, and works like a forum. The difference is that messages posted in this system can include information to express the sender’s affective state (e.g. happy), interpersonal attitude (e.g. acting friendly or respectfully), reference documents, and comments about such documents. TelMeA has an editor that allows users to include this kind of information into the messages. Each user is represented by an agent that sends both, the textual and non-textual content. As an avatar, the agent communicates non-textual content by facial expressions (e.g. smiling, nodding). Moreover, TelMeA can analyze the non-textual content to provide a summary of evaluations made by other users [110,111]. A system like TelMeA can be useful for CoPs because it allows users to express themselves in a more comprehensive way. Furthermore, the analysis of the non-textual content can help users to understand the community dynamics. One limitation of such a system is the need of a specific editor to include non-textual information in the message.

CommunityBoard is a system that displays the structure of a discussion graphically. It is formed by a Personal Assistant for each user and a Community Agent. The Community Agent classifies the messages of the discussion according to criteria such as the subject and the sender's reputation. The Personal Assistant presents the structure of the current discussions graphically according to its user's preferences and some criteria such as the author of the message, the subject and the relevance of the message. Each message of the discussion is represented by an icon and its relevance is represented by the type, the position and the shading of the icon. In this way, users can, for example, decide in which discussions to participate, guess who is more knowledgeable on a given topic, visualize the relation among subjects, and identify the relevance of each topic for the community [44]. CommunityBoard is a community-oriented system than could help community members comprehend discussions and their context. It can also help a member participate just in discussions in which he can contribute effectively. Moreover, community coordinators can use the system to monitor the dynamics of the DCoP. The idea of the CommunityBoard could be applied to other means that DCoP members use to interact, such as blogs and wikis.

5.3.2 Discussion

In the research for this review, we were not able to find any agents or multi-agent systems applied to blogs and wikis. Since blogs and wikis can be useful for DCoPs, we believe, they should be taken into account in the research concerning systems to support DCoPs. Agents and multi-agent systems could either support users using blogs and wikis or they could use blogs and wikis to build profiles to personalize the information retrieval. An agent or MAS similar to CommunityBoard could also analyze blogs and wikis to indicate the relevance of their contents.

We advocate that systems that, like the CommunityBoard, analyze the asynchronous communication among DCoP members could be useful for three main reasons: they could support members performing an activity; they could help the DCoP coordination observe what is happening; and they could be used to study the dynamics of a community. We consider that tools allowing researchers to study DCoPs and virtual communities are an interesting research opportunity. Usually, asynchronous communications in DCoPs leave traces (exchanged email messages, blogs, wikis, etc.) that are a potentially rich material to be analyzed. The amount of material could be intimidating because virtual communities tend to be large, thus powerful computational tools to analyze it might be necessary.

It is difficult for DCoPs to be "present" in the daily routine of their members. Asynchronous communications could be used to minimize such lack of "presence." Agents could monitor discussion boards, blogs and wikis to generate an indicator of the activity in the community.

We consider that the content generated by both synchronous and asynchronous communications represents a considerable research material that should be better explored. The study

Table 4 Major features identified in the Publishing category

Major feature	Agents and multi-agent systems
Geographically Co-located Community Information Dissemination	LiMe [99]
Elaboration of Newsletters	CLELIA [3]
Bookmark and Bibliographic References Management	CoWing [52] CommunityItemsTool [56]
Web Pages Collaborative Editing	PAIS [113]
Recommender Systems / Collaborative Filtering and Retrieval	ACORN [16,40,69,72] Community Search Assistant [35] Collaborative Spider [19] Implicit [10,11]
Information Semi-automatic Capture	[108]

of virtual communities (including DCoPs) can lead to better tools for communities and a better understanding of such a social phenomenon.

5.4 Publishing

The Publishing category includes systems that help publish documents and use document repositories. The category was extended (considering Wenger et al. [120] original conception) to include tools to handle (create, save, manage, etc.) documents. So, in this paper, we included other tools like systems to automatically capture information and organizational memory systems.

In order to provide an overview of the available tools, we classified them according to their major features. In the Publishing category, we identified six major features: Geographically Co-allocated Community Information Dissemination, Elaboration of Newsletters, Web Pages Collaborative Editing, Information Semi-automatic Capture, Recommender Systems/Collaborative Filtering and Retrieval, and Bookmark and Bibliographic References Management (Table 4).

5.4.1 Descriptions of the systems

In the Publishing category we included two singular systems: LiMe and CLELIA.

Living Memory (LiMe) is a system developed to support geographically co-located communities like neighborhoods. The goal of the system is to share information (e.g. local news, “lamppost announces”) among community members. The system combines specific electronic devices and a multi-agent system. The employed electronic devices include personal devices, like home PCs and mobile phones; and shared devices, like Interactive Tables and Interactive Bus Stops. Interactive Tables are tables with which people sitting around can interact with LiMe, as a collective use multimedia kiosk. The Interactive Bus Stop device allows people to interact with the system while waiting for the bus. The MAS is composed of three types of agents: Personal Service Agent (PSA), Location Service Agent (LSA) and Memory Service Agent (MSA). The PSAs play three main roles: personal profile manager, acquaintance model manager and personal history manager. As a personal profile manager, the PSA manages a community member’s individual profile. As an acquaintance model manager, it stores the user’s social circle and his/her activities in the different communal locations. As a personal history manager, the PSA maintains a log of the user's interactions with communal content. LSA manages the model of the location where a static device is situated. It manages the location profile and history as well as the profile of location neighborhood. MSA plays the role of information disseminator, relevance monitor, archivist, garbage collector and link manager [99].

LiMe has been developed for a co-located community in which the participation is more an alignment instead of the engagement usually found in professional communities. But the system presents an interesting way to handle individual and communal profiling. Moreover, LiMe has an acquaintance model that could be useful for DCoP members that participate in different communities. The acquaintances of a DCoP member could help to define him and in this sense, they should be part of his profile. A model that maintains information about the activities a member performs in a given location, could be helpful to personalize the support to members when they enter a specific "spot" (e.g. a tool or a feature in a system) in the community "virtual world" (i.e. the platform the community use to perform its activities).

CLELIA is a MAS developed to facilitate the publication of information by performing page editing automatically. It is aimed at overcoming limitations of the current publishing sequential workflow by allowing information creation and its publication simultaneously. The system is composed of three main agents: Section Agent, Page Agent and Element Agent. Section Agents receive all the elements of the section to determine the number of pages that will be used and to define the elements of a single page. Page Agents place the elements into a page. Element Agents store information about each element [3]. CLELIA presents features that can be useful for communities that are performing tasks like the elaboration of newsletter, manuals or web sites. CLELIA seems to be limited to a restricted task and thus it would be useful for DCoPs with a very specific profile.

Less complex than CLELIA, Proxy Agent-based Information Sharing (PAIS) can be used to help communities to publish web pages that are being elaborated collaboratively. Its major component is Wedit. Web browser-based Direct Editing (Wedit) allows users to edit HTML text using a Web browser. PAIS, as a whole system, enables users who participate in a community to share information. A community member could edit a web page using Wedit and other members could see the modifications through a Web browser. The system merges the modifications with the original page (that is not modified) each time a community member accesses it [113]. Communities could use the system to build web pages collectively. For example, sub-communities could use systems such as PAIS to publish their activities. Another advantage of the system is that it seems to be simple and inexpensive. PAIS could be useful for DCoPs, but it seems to us that a wiki could be used to support the execution of the same kind of task.

To share information using PAIS, users should make it available through web pages. But, there are systems that can semi-automatically capture information and knowledge. Tacla and Barthès [108] present a system that captures and makes available lessons learned during the development of R&D projects. It also helps users organize their documents. A Personal Agent (PA) is the interface between each user and the system. The user invokes services like organizing documents or sending emails through a PA. The services themselves are implemented by Service Agents (SA). As the SAs work in a structure called "coterie," there is a broker agent that can create a communication link between different "coteries." A "coterie" is a tightly linked group of agents [5,108]. An agent able to capture lessons learned from the activities of a community member can be useful to build a "lessons learned" library to a given community. It is a way to improve the efficiency of the process of experience reification. Such reified experience, as lessons learned, can be used in the process of negotiation of meaning while the community is facing a similar situation. To reify the experience is important, but it is also important to be able to adapt and modify such an experience. Thus, the system should also allow community members to question and modify the learned lessons.

DCoPs can also be supported by a system that recommends documents. Agent-Based Community-Oriented Retrieval Network (ACORN) is a community-oriented MAS that aims at improving the communication among the members of a community. In this system, each document or query is an agent. Each agent can introduce itself to users that could find its information useful. The user can recommend the offered information to other recipients that could also find it interesting. In doing so, ACORN mixes recommendations generated automatically with those elaborated by humans [16,69,72]. A system like ACORN can be useful to disseminate information among community members.

Gomez-Sanz and Pavon [40] also present a system to recommend documents. In such a system, documents are evaluated using annotations made by some community members. If the document evaluation is positive, the system recommends it to the whole community. To organize the process of dissemination, the MAS uses a workflow. The process begins when a community member indicates a document that is evaluated automatically, considering the community profile. If the document is evaluated positively, it is evaluated by humans who apply certain social rules. To achieve the ideal composition of the community, the system can punish users with undesirable behavior (e.g. non evaluation or individual negative evaluation of a document with collective positive evaluation). Document recommendation can be useful if integrated into the CoP practice. Although the idea of using a workflow could be considered interesting to manage the flow of document dissemination, it seems inadequate for a community to have a mechanism that tries to achieve an "ideal composition" of the community. Diverging points of view do not mean inadequacy for a given community.

Another type of document recommendation systems is the one that relies on automatic collaborative filtering. The Community Search Assistant allows a community to search the web collaboratively. Each time a community member makes a query, the query is stored as a graph. The stored queries can be linked by the relatedness of the documents found in the search. When a community member is about to perform a new search she can follow the network of queries. In this way, the collective knowledge, embedded in the network of queries, can help a community member to articulate one's information needs using appropriate terminology [35].

Collaborative Spider is a MAS for collaborative information retrieval and web mining. The system supports collaboration by sharing search sessions containing post-retrieval analysis. In a given group, each user controls a User Agent and the group shares a Collaborator Agent and a Scheduler Agent. The User Agent can fetch and analyze web pages. It also shows graphically the search and analysis results, and the annotations elaborated by group members about the documents. The Scheduler Agent keeps a list with the retrieval and analysis tasks scheduled by the users and performs such tasks. The Collaborator Agent recommends documents to users based on their profiles. It also keeps users search sessions, their profiles and the track of their annotations. The annotations can be attached to the documents and consulted by other users [19]. Community Search Assistant and Collaborative Spider could be useful to support some communities not just because they could help members find information but also because they could help newcomers understand the terminology and access references adopted by the community.

Implicit [10,11] is a MAS that recommends documents based in the notion of Implicit Culture. Implicit Culture, a generalization of collaborative filtering, helps a newcomer to a community behave like an old-timer, but without having explicitly explained the knowledge needed to do this. When a user sends a request to the system, it suggests specific information that was obtained by observing the old-timers' past behaviors when requesting similar information. Implicit combines results of a search engine (Google) with the information obtained from the analysis of the users' behavior.

Systems to recommend documents and to filter and retrieve information can facilitate the dissemination of information inside a DCoP. They can also help accelerate the integration of newcomers. When newcomers use such systems to search for information, they would use the experience of the old timers that is embedded in the systems. A possible improvement for this kind of system should consider that a person participates in several communities and has her private interests.

Collaborative Web Indexing (CoWing) is a distributed collaborative bookmark system that enables users to share their bookmarks. The system does not impose extra workload on the users; it allows users to choose who can access their bookmarks, assists users in classifying their bookmarks and recommends interesting bookmarks [52].

Like CoWing, CommunityItemsTool also allows community members to share bookmarks. Besides bookmarks, CommunityItemsTool enables users to share bibliographic references and annotations about bookmarks and these references. Data can be published and accessed through a web browser. The system also includes a collaborating filtering feature and a subscription mechanism. The search can be made based on several attributes like: title, author, categorization or user ratings. Users can also subscribe for recommendations based on the same kind of attributes [56]. Systems like CoWing and CommunityItemsTool could help newcomers in a community to access quickly the references used by the old-timers, therefore accelerating their integration. Such systems would be improved if they could classify and search for bookmarks and bibliographic information using information extracted from the content of the documents themselves.

5.4.2 Discussion

In the publishing category, document recommendation, as well as collaborative filtering and retrieval have been actively explored, but we consider that a relatively unexplored feature is the (semi)automatic capture of information from documents and the traces left by the communication between community members. Information extracted (semi)automatically from such sources could be used to elaborate new documents [109].

Agents could be used to inspect synchronous and asynchronous communication between members and support the elaboration of documents concerning the main points of the discussion. For example, agents could inspect the messages of a discussion board; extract some answers for a question; and save them as a Frequent Asked Question.

5.5 Community cultivation

Communities of practice could be considered as living entities that go through a life cycle: they start, grow, mature and die. In this context, it is pertinent to talk about cultivating communities. Cultivating communities relates to accepting, supporting as well as understanding the kind of role communities can play in an organization. Excess of management (and consequent control) can undermine and kill a community as well as the lack of support for community activities [119]. Following that reasoning we chose tools that could help cultivate communities during their lifecycle. The Community Cultivation category includes tools to form communities by putting together people with similar profiles.

In order to provide an overview of the available tools, we classified them according to their major features. In the community cultivation category, we identified four major features:

Table 5 Major features identified in the "Community Cultivation" category

Major feature	Agents and multi-agent systems
Community Presence Indicator	Social Web Cockpit [41]
	Agent-Buddy [126]
Community Formation / Identification	Let's Browse [63] [101–104]
	Community Organizer [44,127,128]
	MEMOIR [26]
	[117]
	[125]
	[124]
	MARS [129,130]
Support to Communities' Activities	Answer Garden 2 [1] ICC [107]
	eLogbook [34]
	KEEx/IVisTo/KARe [94]
Practice Dissemination	K-InCA [85]

Community Presence Indicator, Community Formation/Identification, Support to Communities Activities and Practice Dissemination (Table 5).

5.5.1 Descriptions of the systems

K-InCA is a MAS designed to help users acquire and adopt knowledge sharing practices. The system assists the user during all the adaptation process, starting by the presentation of the desired behaviors and ending with the users' practice within the community. Each user has an agent that intervenes in a personal and contextualized way. Such a personal agent observes the user's behavior and makes suggestions, introduces concepts, and proposes activities in order to achieve the adoption of sharing practices [85]. We consider that K-InCA could facilitate the adoption of knowledge sharing practices, but such a contribution could be limited. It may be difficult to make some practices adopted by communities explicit.

We have identified several tools that could help identify and form CoPs. Although classed as tools for Synchronous Interactions; Community Space and Freewalk could be classified as tools for Community Cultivation as well. Another tool that could be classified into two categories is Let's Browse [63]. It was mentioned in the individual participation category, but we think that it could also be considered as a tool for cultivating communities, specifically helping identify people with similar interests during an event. Let's Browse is a system that allows collaborative web browsing. The system can sense when a person approaches its screen through some special tags. After identifying the people near the screen, the system uses their personal profiles to build an interest profile of the group. Then, based on such a collective profile, Let's Browse recommends web pages and also tells why it chose that specific page. As mentioned, such a system is capable of working as an icebreaker.

Like Let's Browse, the system of [101,103,104] was designed to be deployed in events like conferences or workshops. The system is composed of Personal Digital Assistants (PDAs), infrared badges, Internet connected kiosks terminals and a website. The PDAs can guide the participants in the conference. They can be connected to the kiosks by an infrared interface. There is also a server with several infrared sensors to detect tags' IDs. The PDAs can offer services like browsing the conference program or recommending presentations. The system uses the infrared badges to follow the user, tracing a touring diary (where he/she had been, the attended presentations). Also using the badge, the user can mark a presentation that he found interesting. The information kiosks provide a site map and a semantic map allowing users to browse the semantic relationships among papers, keywords and participants. One of the most interesting features for communities is the AgentSalon, a specialized kiosk that facilitates face-to-face interactions [102]. To stimulate face-to-face interaction, the system promotes chats among personal agents with touring diaries that present some points in common. In this chats, agents can recommend each other presentations or can share the evaluation of a presentation. This system can also be helpful when trying to form communities.

Let's Browse and the systems designed by Sumi and Mase [101,103,104] could be useful to form and identify DCoPs, but they should be deployed in a face-to-face event such as a conference. Such a characteristic limits their possibilities as effective tools to support DCoPs.

SHINE is a framework for the development of communication systems for networked communities. It was used to develop two systems: Community Organizer and Gleams of People. Gleams of People was described in the Synchronous Interaction category. Community Organizer is a tool that can support the creation of new communities by providing a virtual place where people sharing the same interests can meet and communicate. Users can represent their interests in a graphic virtual space through an icon that is associated with a vector of keywords. If two vectors of keywords are similar, the icons are located near each other. The center of the space also has a vector of keywords. As the user changes this vector, the location of the icons changes as well. So users can identify other users with similar interests. The system also allows users to attach messages to the icons and get in touch [44,127,128]. SHINE is an interesting framework because it facilitates the development of communication tools for communities, therefore allowing the development of tools to fulfill specific community needs. Community Organize can be useful to identify virtual communities in connected groups.

The Managing Enterprise-scale Multimedia using an Open Framework for Information Re-use (MEMOIR) system helps users access information and navigate through an intranet. It also can be used to find colleagues with similar interests. The system deploys agents capable of supporting users using trails and links. Trails are sequences of documents used to accomplish a task. Links could be made by users to associate different types of documents. The system can analyze the data and suggest interesting documents or people who could be contacted to achieve a certain task. It also allows users to create trails and links as well [26]. MEMOIR could be classified in the Individual Participation category, but we consider it useful for identifying communities, once it can identify people with similar interests by analyzing their trails.

Another system [117] forms communities observing the behavior of the users. The system monitors and analyzes the behavior of the users during search operations and then assembles users (or their personal agents) with similar interests into communities. This way, the system is able to provide better search results. The system could also help form communities, but it seems more limited than MEMOIR or SHINE.

Yang et al. [125] developed a system that forms small student communities from a larger group that uses a web-based educational system. It aims at promoting interaction among students that share similar interests by grouping them into small communities. A student profile (called Learning Experience Vector) is defined considering his behavior (e.g. the time dedicated to study a document, the frequency of access to online resources) and the contents (e.g. documents) he accesses. Such a profile is elaborated by the Learner Agent that follows the student inside the educational system. Group Agents form small communities by exchanging information with Learner Agents and other Group Agents.

Yang et al. [124] developed an approach to mine distributed communities in networks. The approach is not restricted to the analysis of social networks, but could be useful to identify DCoPs. Their approach can be distinguished from the previous ones because it is more appropriated for handling distributed and dynamically evolving networks. Each node of the network is represented by an agent that operates autonomously and asynchronously. Communities are mined by using the agent's point of view. If we could associate such an approach with a Personal Assistant agent, we could have a valuable tool to identify DCoPs inside social networks.

The aim of the systems described above is to form (or to identify) communities by analyzing similarities among different types of user profiles. But, it is not the only possible approach. People recommendation can also be used to form communities. Multi-Agent Referral System (MARS) is a system that recommends people. Each user controls an agent that stores one's profile and a model of one's acquaintances. In order to send a question to acquaintances, the user receives several recommendations from his agent and he can pick some of them for whom the question is sent. The selected acquaintance agent analyzes the question and decides whether to forward it or not to its user. If the acquaintance's agent considers that the question is not adequate for its user, it can recommend other people to the agent that generated the question. The latter integrates such a recommendation to its own model of acquaintances and decides to send the request or not to its new acquaintances. When the agent sends a question, it evaluates the answer and updates the model of acquaintances [129,130].

Systems supporting the formation and identification of communities are useful during the first phases of the community lifecycle. However, as the community evolves, other types of tools become necessary. One system that could support established communities is the Social Web Cockpit. Social Web Cockpit is a MAS that supports collaboration among members of a established community. It can be used with a common browser and with Basic Support for Cooperative Work (BSCW). When a community member is navigating in a web site, the system can indicate who the other members doing the same are, and if the web site belongs to the community repertory. The system also provides information allowing members navigating the same web site to get in touch synchronously (e.g. through a chat). The Cockpit can facilitate the access to BSCW workspaces with collections of documents or links. Other features in the tools are: user rating of web sites and documents; collaborative search based on other member's searches and creation of a vocabulary for the community [41]. Social Web Cockpit is a tool that supports users to access and manage several information sources like the web and BSCW. Beyond the role of facilitating the access to documentation, this system could be useful to make community members aware of their participation in a community. As the Cockpit window is always shown on the screen, it could help cultivate the community, working as a constant reminder of the community activity.

Another tool that can make the user "feel the presence" of the community is Agent-Buddy. Agent-Buddy could be used with a Computer Support Collaborative Work (CSCW) tool to provide a sense of "togetherness" but keeping the privacy of each user, as the agent distributes selectively the information in the community. The aim of the selective distribution is to keep a "distance" among members. Authors use as analogy the physical distance or the attitude members keep during meetings in co-located communities [126]. We consider that awareness is important to keep distributed communities working. As the distance tends to weaken the links among community members, tools like the Agent-Buddy and Social Web Cockpit could be useful to partially compensate for it.

Answer Garden can be considered as a system to cultivate communities because it can help in the integration of newcomers (by answering questions about the community domain) and provide old-timers a space for discussion. Answer Garden 2 is a system architecture for organizational memory and collaborative help support. As its predecessor, Answer Garden, it helps distributed users through a database of commonly asked questions (FAQ). By using Answer Garden, a user can look for the answer to common questions in a database and if he is not satisfied with the answer, he can post his question to an expert indicated by the system. Then the expert can insert the new answer into the database. Answer Garden 2 is more flexible and can be applied to any information system. When a user posts a question to his Agent Garden 2 client, an escalation agent will forward the questions to several instances (e.g. chat, bulletin board, help desk, human specialist) following previously defined policy (e.g. first the chat, then the bulletin board, and so on). Yang [123] presents a system that can also retrieve FAQ, but Answer Garden 2 has a more collective character because it provides features allowing encounters between newcomers and old-timers. Answer Garden 2 also has features that allow groups of people to collaborate in building answers and information repositories [1]. Answer Garden 2 could be very useful for communities because it has tools for communication and tools allowing the capture and refinement of the knowledge created during the activities performed with such tools. It also facilitates the access to explicit knowledge (databases) and to experts. The idea of an escalating agent seems interesting for communities. Such a mechanism could be applied to distribute questions among members with different types of participation. For example, a newcomer could post a question and this question could be asked first to the other newcomers and after to the active members, only then to the core group.

The eLogbook system aims at supporting the management of tacit and explicit knowledge inside CoPs. It presents features for assets management, activities management and a platform for discussions. eLogbook is based on the 3A model (Actors, Activities, Assets) which considers three entities: “actors” that perform “activities” using “assets/artifacts.” The system offers three types of graphical interface: context-aware interface, content oriented interface and the two dimensional maps interface. The content-oriented interface displays the list of entries for each entity (e.g. list of actors, list of activities). The two dimensional interface presents the same lists but in a network format to highlight the relations among entries. The content-aware interface integrates three regions, each one dedicated to one of the entities (actor, activities, and assets). When the user chooses an entry (a person, a resource or an activity), the correspondent region is dislocated to the center of the workspace. The other regions are updated to highlight the entries that have a link with the chosen entry. Each region presents icons that indicate which operations are available in the region. With eLogbook, each user can create his own virtual workspace with the necessary entries (e.g. activities that the user is participating in, and people with whom the user is working) [34].

Knowledge Enhancement and Exchange (KEEx) is an organizational learning environment that uses a peer-to-peer architecture. It allows users to search and share artifacts, even without using a common representational language or an ontology. Each user makes public her knowledge using a hierarchy of concepts (that give a context to an artifact) that contains the pertinent artifacts. When searching for information in an artifact, the user elaborates the request for the information using keywords or the context of the information. KEEx examines other users’ hierarchy of concepts and returns a list of users, contexts, and artifacts. To do it, the system uses a sophisticated algorithm to match the request and the available contexts. It also counts on user profiles that are built by means of manned interviews and the observation of users’ behavior (performed by the system through the personal assistant agent). KEEx is the foundation of two other tools: Interactive Visualization Tool (IVisTo) and Knowledgeable Agent for Recommendations (KARe). IVisTo is a tool allowing the visualization of the relevance of request results. The relevance of a result is determined by using the users' social and semantic preferences. The social preferences are represented in the user profiles by variables such as trust, position, etc. The semantic preferences are determined by KEEx. The user can define the weight of the social and semantic factors in the computation of the pertinence. KARe is a MAS designed to recommend both documents and people that can provide the information requested by the user. It also uses social and semantic preferences to elaborate the recommendations [94].

Intelligent Conversational Channel (ICC) is a system that can be used to share knowledge about researchers in a given domain. It is based on the extraction of information from documents, especially from scientific papers, and from the interactions among community members. ICC allows users to interact with other users and agents. Thus, when a user asks a question, the answer can come either from a user or from an agent. To answer questions, agents use information extracted from documents and from the interaction among members [107]. ICC could be useful to integrate newcomers to a CoP by helping them identify knowledgeable community members, the relevance of their contributions, their partners, etc.

5.5.2 Discussion

One can observe that the issue of systems being able to identify or form virtual communities has been studied actively. However, we conclude that the development of systems using agents or multi-agent systems to support activities performed by DCoPs, such as KEEx and eLogbook, could be further explored. The development of groupware dealing with a similar set of issues provides a strong foundation for the development of systems to support DCoPs, but still leaves some open issues. For example, one major concern in the study of DCoPs is individual and collective learning. Trajectories represent individual learning and the evolution of community practice represents collective learning. We believe that such a concern is still neglected in the development of systems supporting DCoPs.

Although potentially useful, the approach used to develop most of the systems to cultivate communities has shown some limits. We think that an approach based on the ability of multi-agent systems to integrate different features (new or provided by legacy systems) by using agent wrappers in an open environment could give birth to more appropriate systems. As DCoPs go through a life cycle, they tend to change their needs with time. Systems integrating new features or using agents to encapsulate legacy systems or features might help deal with such evolving needs.

Agents and MASs could also provide another kind of integration: the integration of different interfaces. Different from a typical situation when a DCoP member should use different systems with different interfaces to accomplish his activities, a user could use a personal agent to access different systems [109].

We conclude that there is a lack of features that support the coordination of DCoPs among the systems surveyed in this paper. As DCoPs should be managed with a "light hand" [119], one way to support DCoPs coordination is to generate information about, for example, the participation of their members, trajectories or the evolution of the practice [87].

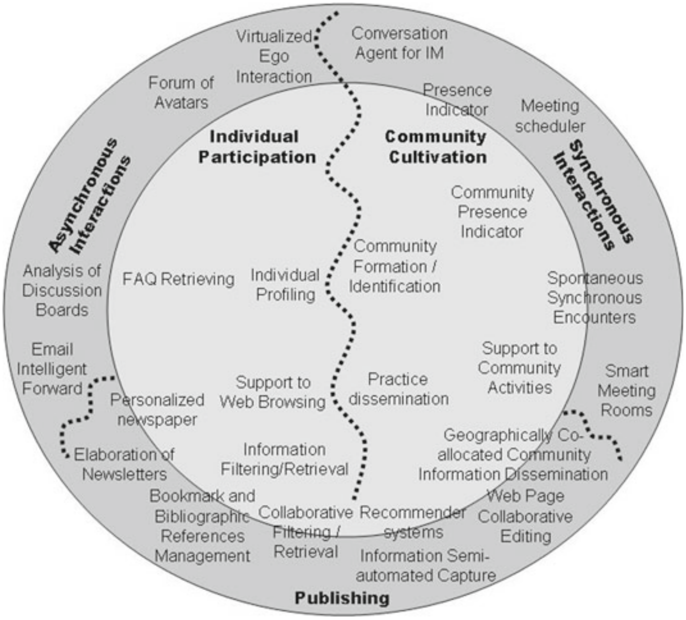

Fig. 2 MAS applications to support communities

5.6 Applying Agents and MAS to support communities: a general vision

We presented several multi-agent systems and agents able to support distributed CoPs and classified them into five categories: Individual Participation, Synchronous Interactions, Asynchronous Interactions, Publishing and Community Cultivation. In each category, we grouped a set of systems by their features. In order to provide a representative landscape of such systems, we graphically indicated the major features found within the ensemble of the analyzed tools (Fig. 2) in the diagram proposed by Wenger et al. [120].

In order to link each system to its category, we built a table establishing the relations between each system and one of the five categories through its features (Table 6).

5.7 Current and potential contributions to the support of DCoPs

The idea of this survey was to review a number of MAS applications and analyze in which way they could support activities performed by DCoPs as well as to expose potentially useful new features. In this sub-section, we summarize both issues: the contribution of the current features (Table 7); and potentially useful new features (Table 8).

6 Concluding remarks

In this paper, we presented a review of agent and multi-agent systems containing features that could be used to support communities. Such a review is not intended to be exhaustive but rather comprehensive enough to present a landscape of the systems that are available or could be developed for supporting of DCoPs.

Table 6 A landscape of MAS applications to support communities

Category	Major feature	Agents and multi-agent systems
Individual Participation	Individual Profiling	SUITOR [65]
	Personalized Newspaper	WebMate [20]
		NewsAgent [38]
		ETTS [15]
	Support to Web Navigation	[53]
		[96]
	FAQ Retrieval	Yang [123]
	Information Filtering/Retrieval	AgentRAIDER [90]
		Watson [14]
		MAIS [29,30]
		MAPIS [81]
		[51]
		[98]
		[88]
		[95]
		Personal Search [37,38]
		Several examples [55]
Synchronous Interactions	Presence Indicator	Gleams of People [127]
	Conversational Agent for IM	AINI [39]
	Meeting Scheduling	[22]
		[59]
		RESCH [62]
		MSRAC [8]
		[89]
	Spontaneous Synchronous Encounters	Contact Space [83]
		Freewalk [49,75,76]
	Smart Meeting Rooms	Smart Conference Room [45]
		EasyMeeting [21]
		MITRE ETR [43]
Asynchronous Interactions	E-mail Intelligent Forward	D-mail [64]
	Forum of Avatars	TelMeA [111,110]
	Analysis of Discussion Boards	CommunityBoard [44]
	Virtualized Ego Interaction	EgoChat [57]
Publishing	Geographically Co-located Community Information Dissemination	LiMe [99]
	Elaboration of Newsletters	CLELIA [3]
	Bookmark and Bibliographic References Management	CoWing [52]
		CommunityItemsTool [56]
	Recommender Systems/Collaborative and Retrieval	ACORN [69]
		[40]
		Community Search Assistant [35]

Table 6 Continued

Category	Major feature	Agents and multi-agent systems
		Collaborative Spider [19]
		Implicit [10,11]
	Web Pages Collaborative Editing	PAIS [113]
	Information Semi-automatic Capture	[108]
Community Cultivation	Community Presence Indicator	Social Web Cockpit [41]
		Agent-Buddy [126]
	Community Formation / Identification	Let's Browse [63]
		[101–104]
		Community Organizer [44,127,128]
		MEMOIR [26]
		[117]
		[125]
		[124]
		MARS [129,130]
	Support to Communities' Activities	Answer Garden 2 [1]
		ICC [107]
		eLogbook [34]
		KEEx/IVisTo/KARe [94]
	Practice Dissemination	K-InCA [85]

In order to organize the study, we adopted the categorization elaborated by Wenger et al. [120] who established categories based on the usual kinds of activities that are performed by communities: Synchronous Interactions, Asynchronous Interactions, Publishing, Community Cultivation, and Individual participation.

For each category, we grouped the identified systems by features (e.g. Personalized Newsletter, Community Formation/Identification, etc.). Then, we located each feature in the diagram elaborated by Wenger et al. [120]. The idea is to facilitate the visualization of the relations among categories and features. Finally, to link categories, features and systems we built a table that summarizes the results of this review.

Despite the fact that most systems in the Individual Participation category do not consider participation in groups, they could be useful as tools to perform individual activities while participating in communities. User profiles are necessary to adapt a tool to the users and, at the same time, they can also be used to identify and form communities. A personalized newsletter or a system retrieving information from distributed sources could improve users' efficiency when accessing information on personal interests or community domain. Even a system oriented toward communities should consider the individual dimension. An individual can participate in several communities, and develop a different aspect of one's identity in each one of them. When he is engaged in the activity of a specific community, he "wears" the correspondent aspect of his identity. Thus, even a system for communities should consider individual participation.

The features identified in the Synchronous Interaction and Asynchronous Interaction categories could be useful for face-to-face interactions and technology mediated interactions, respectively. Meeting scheduling and smart meeting rooms are systems dedicated to the

Table 7 A summary of contribution of the current features to the support of DCoPs

Major feature	Current contribution
Individual Participation	
Individual Profiling	Profile builders can help provide personalized services to community members
Personalized Newspaper	Personalized newspapers and clippings could help DCoP members keep track of modifications in information sources regarding the community domain
Support to Web Navigation	Systems to support web navigation could help DCoP members find information in the World Wide Web more efficiently
FAQ Retrieval	FAQ retrieval could be used to accelerate the integration of newcomers in DCoPs
Information Filtering/Retrieval	Information filtering and retrieval using different types of profile can help community members find, in an easier way, information required to perform communal activities
Synchronous Interactions	
Presence Indicator	Presence Indicators can be useful to reinforce the presence of members of distributed communities. It can be used to prompt spontaneous encounters
Conversational Agent for IM	A conversational agent could be useful to animate chat sessions. It could be also used to help integrate newcomers
Meeting Scheduling	Meeting scheduling systems are useful to organize face-to-face events organized by the DCoP
Spontaneous Synchronous Encounters	Spontaneous Synchronous Encounter systems can mimic the socializing effect of spontaneous encounters
Smart Meeting Rooms	Smart Meeting Room systems are useful to organize face-to-face events organized by the DCoP
Asynchronous Interactions	
E-mail Intelligent Forward	An E-mail Intelligent Forward system can be used to identify potential members when a community is being formed. It can also be used to identify sub-communities inside a large community
Forum of Avatars	The use of avatars can allow DCoP members to express themselves in a more comprehensive way. The analysis of the non-textual content (e.g. emotions) expressed by the avatars can help users to understand the community dynamics
Analysis of Discussion Boards	Analysis of Discussion Boards system could help DCoP members to comprehend discussions and their context. It can help them participate just in discussions in which they can contribute effectively. Community coordinators can use the system to monitor the dynamics of a DCoP
Virtualized Ego Interaction	Virtualized Ego Interaction systems could be used by newcomers trying to learn about the DCoP domain, accelerating their process of integration. It can also help newcomers feel more comfortable because they interact with a virtualized ego before interact with community old timers
Publishing	
Geographically Co-located Community Information Dissemination	
Elaboration of Newsletters	Systems to elaborate newsletters can be useful for communities that are performing tasks like the elaboration of newsletter, manuals or web sites
Bookmark and Bibliographic References Management	Bookmark and Bibliographic References Management systems could help newcomers in a DCoP access quickly the references used by the old-timers, therefore accelerating their integration

Table 7 Continued

Major feature	Current contribution
Web Pages Collaborative Editing	Systems to build web pages collectively can be useful for DCoPs. Sub-communities could use such systems to publish their activities
Recommender Systems/Collaborative Filtering and Retrieval	Systems to recommend documents and to filter and retrieve information can facilitate the dissemination of information inside a DCoP. They can also help accelerate the integration of newcomers. When newcomers use such systems to search for information, they could use the experience of the old timers that is embedded in the systems
Information Semi-automatic Capture	A system to capture information semi-automatically can be used to capture information about the activities that DCoP members are currently performing. It could be used to create a library of lessons learned or best practices
Community Cultivation	
Community Presence Indicator	Systems that indicate the presence of the community could be useful to make members aware of their participation in a community. They could help cultivate the community, working as a constant reminder of the community activity
Community Formation/Identification	Systems supporting the formation and identification of communities are useful during the first phases of the community lifecycle
Support to Communities' Activities	Systems to support communal activities offer features that allow DCoP to perform its activities
Practice Dissemination	A practice dissemination system could facilitate the adoption of knowledge sharing practices

face-to-face interactions, while forums of avatars and analysis of forums are features for computer mediated interactions. Community oriented systems should consider integrating tools to enable both kinds of interaction since communities promote both local and computer mediated events. In other words, community oriented systems should consider the constraints imposed by temporal and spatial dimensions.

Although the systems that compose the Publishing category were not conceived specifically for CoPs, they can be useful to facilitate the negotiation of meaning inside a community. The negotiation of meaning is composed of two processes: the reification and the participation. Systems in the Publishing category could support the reification process by capturing information semi-automatically or by supporting the collaborative elaboration of a newsletter. They could also facilitate the participation by recommending documents and people. Although reification is not limited to the creation of documents and participation is not just retrieving them, systems in the publishing category could still contribute to the negotiation of meaning process.

Some of the systems in the Cultivating Communities category, such as Answer Garden 2 and Social Web Cockpit, are not specifically designed for communities, but they were conceived as groupware to support collaborative work. Although KEEx and eLogbook also use notions from the CSCW domain, they are more specific for communities. They emphasize the relations among people, artifacts and activities. KEEx presents the relations among people considering the similarity of interests and the trust. eLogbook constantly presents the relation among people, artifacts and activities. We consider that the emphasis on such relations might foster the development of more adequate systems for communities.

Table 8 A summary of the new features that could contribute to the support of DCoPs

Major feature	Possibly useful new features
Individual Participation	
Individual Profiling	To improve users' profiles, models and preferences considering other dimensions of the notion of identity such as multi-membership and trajectories
Personalized Newspaper	To use profiles that better represent other dimensions of the notion of identity such as multi-membership and trajectories
Support to Web Navigation	Systems to support web navigation could be more useful if they could offer the same kind of services (e.g. bookmark maintenance, verification of updates, suggestion of web pages) for the community as a whole
FAQ Retrieval	Systems to extract FAQs automatically or semi-automatically from sources such as community forums or chats
Information Filtering/Retrieval	To use profiles that better represent other dimensions of the notion of identity such as multi-membership and trajectories
Synchronous Interactions	
Presence Indicator	Personal Assistant Agents could be an option to implement tools to unify the interface to all Internet systems that require information about presence and status
Conversational Agent for IM	
Meeting Scheduling	Meeting scheduling systems could be more useful if adapted to facilitate the organization of on-line events (e.g. chats) organized by the DCoP
Spontaneous Synchronous Encounters	Spontaneous Synchronous Encounter systems could be extended to promote such kind of encounter in open systems like the Internet
Smart Meeting Rooms	Smart Meeting Room systems could be more useful if adapted to facilitate the organization of on-line events (e.g. chats) organized by the DCoP
Asynchronous Interactions	
E-mail Intelligent Forward	To use profiles that better represent other dimensions of the notion of identity such as multi-membership and trajectories
Forum of Avatars	The forum of avatars should include an integrated editor for textual and non-textual information
Analysis of Discussion Boards	Other means that DCoP members use to interact such as blogs and wikis could be analyzed
Virtualized Ego Interaction	
Publishing	
Geographically Co-located Community	
Information Dissemination	The system that presents such a feature has an acquaintance model for each user. Such a model represents the social circle and user's activities in the different communal locations. An acquaintances model could be useful for DCoP members that participate in different communities
Elaboration of Newsletters	The system with this feature seems to be limited to a restricted task and thus it would be useful for DCoPs with a very specific profile

Table 8 Continued

Major feature	Possibly useful new features
Bookmark and Bibliographic References Management	Bookmark and Bibliographic References Management systems would be improved if they could classify and search for bookmarks and bibliographic information using information extracted from the content of the documents themselves
Web Pages Collaborative Editing	It seems to us that a wiki could be used to support the execution of the same kind of task
Recommender Systems/Collaborative Filtering and Retrieval	Recommender systems and collaborative filtering and retrieval systems could be an improvement in considering that a person participates in several communities and has its private interests
Information Semi-automatic Capture	A system to capture information semi-automatically should be also able to allow community members to question and modify such information
Community Cultivation	
Community Presence Indicator	
Community Formation/Identification	Systems supporting the formation and identification of communities could use profiles that better represent other dimensions of the notion of identity such as multi-membership and trajectories
Support to Communities' Activities	Systems to support communal activities should be able to integrate systems and features in an open environment. They should be designed using abstractions like trajectories and negotiation of meaning that are presented in the CoPs' theoretical framework
Practice Dissemination	A practice dissemination system is limited by the kind of practices that could be made explicit in the system

It is possible to observe a significant number of agents or multi-agent systems belonging to the Individual Participation and to the Publishing categories. However, the Synchronous Interactions and Asynchronous Interactions categories are not well covered by the MAS approach, especially for distributed communities.

In the Community Cultivation category we find interesting systems, especially for community formation/identification. We consider that, in this category, there are some important types of community activity that are still unsupported such as community coordination, community reflection, and gathering of community indicators. In addition, in this survey we did not find tools that enable researchers to study distributed communities.

When analyzing the map developed in this review, we consider that agents or multi-agent systems are good candidates for supporting DCoPs, for example through personalized information retrieval, meeting scheduling, discussion board analysis, or community formation or identification. Clearly most such features are also proposed by traditional (non agent) products. However, there does not seem to be any reasonable way to combine such traditional products easily. On the contrary, an agent approach can enable this integration, while adding agent wrappers to encapsulate features or systems, and personal agents to unify interfaces.

Moreover, agents and multi-agent systems could be used to provide new features. We consider that users' profiles better reflect the notion of identity if a MAS is used to represent the multiple aspects of the identity. Indeed, it is possible to envision a MAS in which each agent would represent one aspect of an identity and would negotiate the importance of this aspect in a given context. Identities also change in time, thus profiles or user models should consider their temporal dimension. Profiles should be updated with current information about their user and obsolete information should be eliminated.

Agents could also be used to follow DCoPs members in order to gather data to represent some aspects of a member's trajectory in a community. Data collected by agents could be also used to partially describe the evolution of the practice of a community. As DCoPs usually interact through technological tools, their members leave traces of their activities. Data can be gathered from forums, discussion boards, blogs, wikis, chats, etc. We think that the availability of such information constitute a valuable research material. Moreover, such data could be used to support members performing an activity, or help the DCoP coordination observe what is happening, or build users' profiles or models.

Since DCoPs meet in virtual environments, systems for scheduling meetings and controlling meeting rooms would be more useful if they could be applied to on-line events such as chats, web seminars or videoconferences.

Agents and multi-agent systems should also be applied to capture information automatically or semi-automatically. For example, they could extract some answers to a question posted in a discussion board or in a chat and save them as Frequently Asked Questions.

We consider that several aspects of the development of agents and multi-agent systems to cultivate DCoPs should be investigated. In particular: the development of an integrated open MAS to support DCoP activities; and features in such a system for managing its coordination.

Such examples illustrate the possibilities opened by MAS applications and agent technology.

In the context presented above, we consider that the association between agent and multi-agent technologies and DCoPs have the potential to bear fruits that could affect, in the long term, the way humans and artificial agents interact.

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