Semantic Representation for Collaboration Trajectories in Communities of Practice

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Abstract. In communities of practice (CoP), learning occurs through constant interactions of their participants. The social aspect is fundamental for the construction of knowledge. This work uses semantic web technologies and ontologies to structure and represent the interactions of CoPs participants around a dynamic user profile. This user profile describes a set of dispersed properties and relationships in CoPs, allowing collaborative trajectories recovery in these learning environments.

Keywords: Communities of practice · Semantic web · Ontologies
User profile · Collaboration trajectory

1 Introduction

Communities of Practice consist in groups of people who share a common interest and learn through continuous interactions [1]. The learner is an active agent that establishes relations, produces and socializes knowledge [2]. The social character of a CoP is fundamental to the knowledge construction process. It is through user interactions that bonds are created, experiences are shared, and the knowledge is explicited. For this reason, this work investigates how the dynamics of CoPs can be represented to describe collaboration trajectories in the context of learning, and try to answer the following question: is it possible to build a knowledge base capable of capturing the dynamic and distributed aspect of the interactions in communities of practice?

In order to answer this research question, we propose the use of semantic web technologies and ontologies to describe the relationships among the CoPs, their collaboration tools, contents and participants. The construction of this knowledge base will be explored to define a user profile that evolves while the participants interact and learn through regular exchanges. This dynamic profile allow us to represent collaboration trajectories, which map a group of properties and describe the forms of relationships that may occur in communities of practice, according to the 3C Collaboration Model [4].

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2 Background

User profile is the process of managing and maintenance information associated with the user [5]. Studies involving information retrieval [6], content recommendation [7], adaptive virtual learning environments [5] and intelligent tutor systems [8] concentrate their efforts on this development. Knowledge, goals, interests, experiences and context are some of the information represented in user models. Intelligent tutoring systems handle user profile looking for recognizing student difficulties to offer guidance that facilitates their learning process [9].

In the CoPs context, the user interactions will be captured in order to follow, trace and analyze their learning path. The purpose of this approach is to identify the collaboration degree and the intensity of relations about CoPs participants in collaborative activities. The dynamic user profile consists of the semantic representation of the user interactions and involves the information sources relationship to their activities in the community. The capture and description of these actions will be used to represent the user collaboration trajectory in a given community.

Several researches use semantic web technologies to formalize user profiles [7,10,13], communities of practice [11,12] and collaboration in online communities [14,15]. These technologies associated with ontological representations promote structural, syntactic and semantic interoperability of information. The reuse of ontologies like FOAF (*Friend of a Friend*) and SIOC (*Semantically-Interlinked Online Communities*) also contribute to promote the information interoperability [13,15]. FOAF ontology [17] allows representing people and their social relationships. SIOC ontology [16] provides a vocabulary to represent online communities and user-generated content.

In this work, we have applied semantic web technologies and an ontological representation, reusing FOAF and SIOC, in order to achieve a profile interoperability. This approach extends the possibilities of acquisition and information exchange, and allows services sharing between applications. In addition, it is fundamental to provide computational structures that manipulate and make it possible to extract knowledge about the stored information in an autonomous way. As a result, services using ontologies, are capable of extending their capacity to build knowledge, to perform inferences, to retrieve content from different servers, to stimulate the relationship between users and to engage individuals in a permanent learning environment [7].

3 Communities of Practice Platform

The Communities of Practice Platform CoPPLA [2], used in this experiment, consists of a set of communication and collaboration tools for the instrumentation of CoPs. These tools include manipulation of texts, images, web pages, links, events, discussion forums and spaces for learning experiences. Participants have the ability to create and manage their communities as a space to share knowledge involving learning activities. Projects developed with the CoPPLA involve

knowledge exchange through the conduction of collaborative learning activities. The CoPPLA environment provides the support for network interactions and the sharing of practices with collective access for simultaneous exchanges between participants. Figure 1 shows the view of a content in a CoP (center), its domain (top), its participants (right) and some of its collaboration and communication tools (left menu).

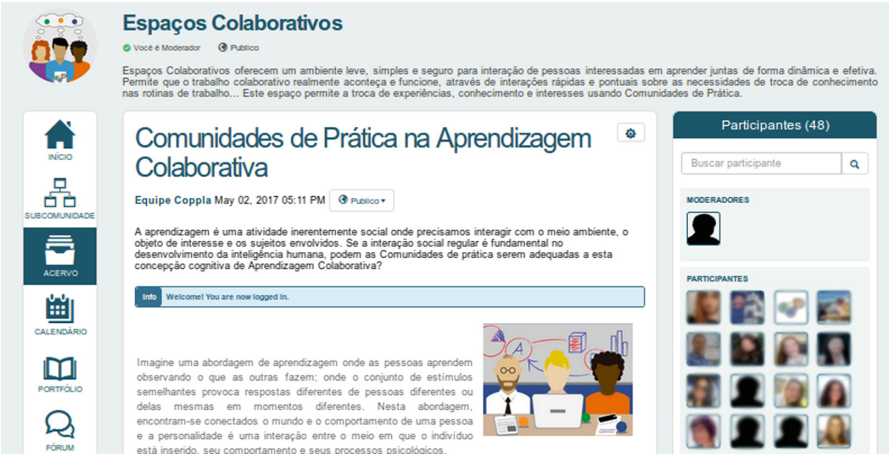

Fig. 1. View of a shared content in a community of practice

3.1 CoPPLA Ontology

In [2], a communities of practice framework is proposed with the objective of providing a semantic knowledge representation model for any CoP Platform (*CoPPLA*). In [3], a reference ontology was proposed in order to describe a general user profile in CoPs. This model focus on communities representation, its participants, interest profile and domain. The user profile has an identity, interactions, interests, roles and skills, classified in two levels: static and dynamic profile. In [18], an expanded CoPPLA ontology was conceived through studies on the real model of CoPs to represent the knowledge in a web CoP platform. The relationships proposed are derived from actions that users can perform in the CoPs. The schema also includes FOAF and SIOC concepts.

In this ontology (Fig. 2), the semantic structure of a community of practice (*CommunityOfPractice*) is a subclass of a community (*sioc.Community*). The community has a set of practices (*has_practices, Practice*) related to a domain of interest (*related_domain, Domain*). An online community (*sioc.Community*) has associated users (*has_user, sioc.UserAccount*) and a user is an extension of the semantic representation of SIOC online user. In addition, the user is associated with an FOAF representation (*account_of, foaf.Person*). The users

(*sioc.UserAccount*) create content (*has_creator, sioc.Item*) in the CoPs' spaces for collaboration (*sioc.Container*). In these spaces the actions (*Action*) of the participants (*agent, foaf.Person*) happen. These actions may be related to interaction (*InteractionAction*), search (*SearcAction*), organization (*Organize-Action*), update (*UpdateAction*) or access (*ConsumeAction*) to the CoP content.

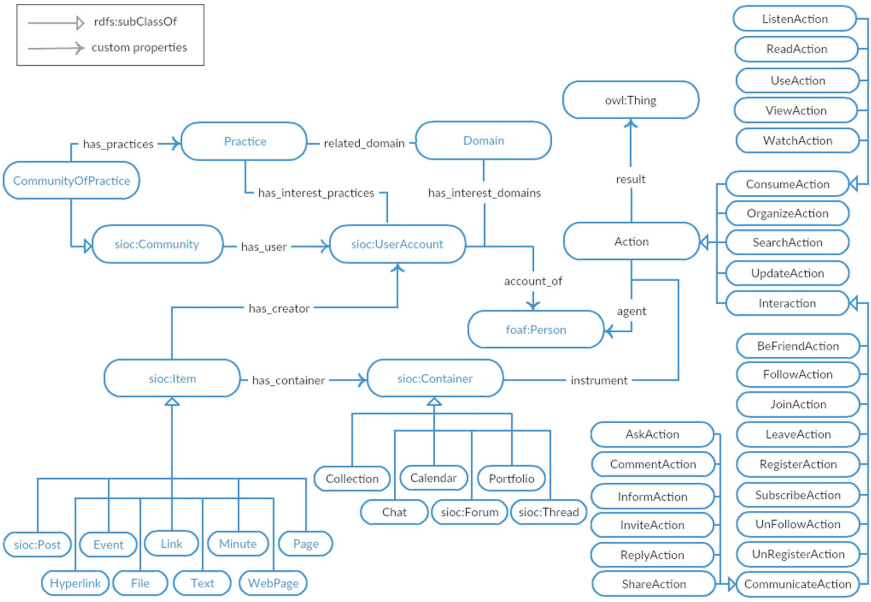

Fig. 2. Current CoPPLA ontology.

The user activity in a CoP is the result of an action that is part of a relationship set of the CoPPLA platform. These actions can be specialized in actions of consumption (*ConsumeAction*), organization (*OrganizeAction*), search (*SearchAction*), updating *(UpdateAction)* and interaction *(Interaction)*. Therefore, the action class (*Action*) is fundamental to this work since the dynamic profile, the interaction history and the collaboration trajectory are built from the user's actions.

4 Dynamic User Profile Manager

The dynamic profile manager organizes the dispersed interaction information inside the CoPs into a user profile with associated semantics. With the help of a semantic server, this profile allows to execute a series of queries and inferences evidencing complex relationships between the participants and the knowledge distributed in the environment. As shown in Fig. 3, the profile manager operates between the communities of practice platform and the semantic server.

The manager is implemented over the *Tornado Python* web framework. Communication between the CoPPLA platform and the profile manager happens through *REST* (REpresentational State Transfer) interfaces and data in *JSON* (JavaScript Object Notation) format.

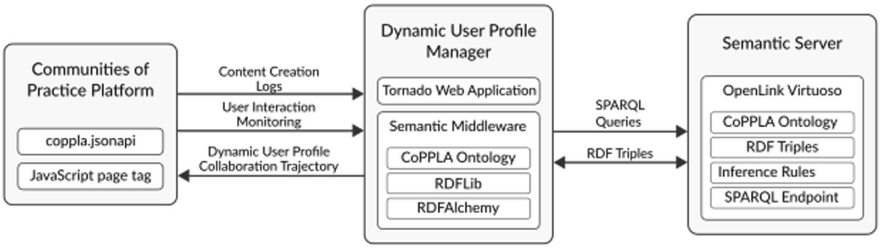

Fig. 3. Dynamic user profile manager overview

The CoPPLA platform implements an *API* (Application Programming Interface) for queries to its database and a Javascript algorithm that monitors and sends information of user interaction to the profile manager. The profile manager provides an *API* to receive information about user tracking and implements an interface to recover the user's dynamic profile and their collaboration trajectory.

The profile manager describes user information with RDF triples and sends them to the semantic server storage. For this task, the manager has a semantic middleware that, when receiving user interaction information in JSON format, performs the semantic description using the CoPPLA ontology and the Python libraries *RDFLib* and *RDFAlchemy*. Lastly, the semantic server is implemented on the *Openlink Virtuoso* universal server. The semantic server stores the set of RDF triples resulting from the mapping process and semantic description, is responsible for queries and inferences, and provides a *SPARQL endpoint* for external access. Virtuoso and SPARQL make up the semantic server data layer core, allowing semantic descriptions to be exposed and consulted on the web.

4.1 Acquisition of User Actions

Web analytics is the process that involves collecting, measuring and monitoring aspects of user behavior, combined and transformed into data that may be analyzed [19,20]. When applied to education, the Web analytics techniques are known as Learning Analytics (LA) and Educational Data Mining (EDM) [21]. These techniques are essential for capturing information related to the interaction of participants in learning environments.

In this work, user actions are a subset of the actions (*Action*) described in the CoPPLA ontology. This subset includes access actions (*ConsumeAction*), search (*SearchAction*), and content update (*UpdateAction*). It also includes interaction actions (*InteractAction*) following and unfollowing other users and themes

(*FollowAction*, *UnfollowAction*), participating or stop participating in a community (*JoinAction*, *LeaveAction*) and communication actions (*CommunicateAction*), sharing content (*ShareAction*) and participating in chats (*CommentAction*, *AskAction*, *ReplyAction*). The user profile manager obtains this information using Web analytics techniques in two distinct forms: queries to the communities of practice platform database to acquire information related to the collaboration actions available on the server; and Scripts to follow user interaction and capture information related to content access, sending and receiving messages, searches and contexts where actions occur individually.

4.2 Mapping and Semantic Description

When receiving data from user interaction in JSON format, the manager triggers the middleware responsible for the mapping process and semantic description of the collaborative actions, associating a set of RDF triples to each collaborative action in the community. A comment in the forum of a community of practice, for example, has its semantic description associated with the *SIOC.Post* class. All content shared on the platform generates a set of triples containing title, description, date and time, location published and the participant responsible for the content. A creation event (*ShareAction*) is also associated with the content.

A community of practice concept (*CommunityOfPractice*) consists of a set of spaces for collaboration where participants are able to share news, interact, hold discussions, and maintain organized the collective and individual productions. The spaces mapped in this work are collection, calendar, portfolio, forum and tasks. These spaces are described with classes that are specializations of *SIOC.Container* class and serve as instrument (*instrument*) for the actions (*Action*) in the platform. Every action has an agent (*FOAF.Agent*) that executes it and a context (*context*), date and time (*startTime*, *endTime*) in which it takes place. An action may include the community where it occurred (*location*) and the collaboration tool used (*instrument*) by the agent. The manager has the ability to infer the location and collaboration tool used from the context where the action occurred and from the relationships described in the CoPPLA ontology (*has_container*, *container_of*, *is_part_of_community*, *is_composed_of_container*).

From this mapping, collaboration scenarios with associated semantics are represented, for example: in a community (*CommunityOfPractice*), a participant (*FOAF.Person*) accesses the collection of the community (*Collection*) and shares (*ShareAction*) a text (*Page*). A second user (*FOAF.Person*) views this content (*ConsumeAction*) and leaves a comment (*CommentAction*) for its creator. The creator in turn responds to the comment (*ReplyAction*) and decides to follow the publications of the other user (*FollowAction*).

5 User Profile and Collaboration Trajectory

The dynamic profile is the result of user actions on the platform. The semantic description of these actions increases the expressiveness and the ability to represent the information, allowing reasoning and inferences that may be explored to

find complex relationships distributed in the environment. A simple information that can be retrieved from this representation is the **user interaction history**. This result can be obtained by means of an all-action query (*Action*) where the agent is an user in question. The representation capacity and the dynamic aspect of the profile becomes apparent when it is possible to associate information to its history, such as the number of views of a particular content, the number of users that interacted in the same context, and related subjects and contents.

According to the *3C Model* [4], in order to collaborate, individuals must exchange information (**Communication**), operate together in a shared environment (**Cooperation**) and organize themselves (**Coordination**), assigning responsibilities and supervising each other. Therefore, collaboration includes reciprocity and interdependency between pairs. Based on this definition, this work models an **user collaboration trajectory** as a *historical set of communication actions among participants of CoPs in the same context*. The availability of different tools for collaboration, as well as the ability to share and access content in CoPs, provide the necessary resources for communication and cooperation actions. Coordination occurs implicitly by organizing tools and CoPs structures and the commitments, conventions and vocabularies defined by the participants themselves during communication.

The identification of collaboration in communities of practice is done through a semantic query to relate users only in contexts where more than one participant has interacted by means of communication actions (*CommunicateAction*). Using a semantic query for retrieving communication actions in the same context, the relations between the participants become apparent. This query highlights users who interacted with each other, while describing the path taken by the participant when navigating in the environment. In this way, the collaboration trajectory of a user is inferred from the relationships among participants on the same content, be it through sharing or discussions about a resource.

6 Experiment: A Collaboration Scenario

We have built several scenarios to validate this work. In the great part of these scenarios, the semantic server retrieves static information and the topics of interest from users, the communities of practice, the collaboration tools, the shared content, their related information such as title, description, creation date, agent responsible for sharing and location, the topics marked in the publications, and the sharing actions corresponding to the creation of each content.

The semantic description of a general CoPPLA use case allows us to represent the progressive and dynamic aspect of the user profile built from the interactions and relationships distributed in the platform. A semantic queries usage is proposed to find static user information and explicit relations. Moreover, these queries takes advantage of ontologies, semantic web technologies and the user profile to discover indirect relations and information resulting from reasoning processes over the RDF triples. Three queries snippets and its results will be presented below from the perspective of the user *John*.

User Personal Information: The Query 1 searches for John's static profile information described with the *SIOC:UserAccount* and *FOAF:Person* classes, including their topics of interest. The query selects predicates (*?Predicate*, *?Value*) related to the user and his online account, as showed in Table 1. The user information described with associated semantics contributes to the interoperability of the CoPPLA platform. An external agent with access to the SPARQL endpoint can performs this query and will be able to interpret the results even without knowing how CoPPLA platform works internally. Navigating to the description of the predicate *FOAF:topic_interest*, for example, the agent, human or software, may verify that it is something for which the user has an interest. The same holds true for any property with a formal description.

Query 1. John's personal information.

```
SELECT DISTINCT ?predicate, ?value WHERE {
  {
    ?user foaf:account ?account .
    ?user ?predicate ?obj
  } UNION {
    ?account a sioc:UserAccount .
    ?account ?predicate ?obj
  }
  OPTIONAL { ?obj rdfs:label ?label . }
  BIND ( IF(?label, ?label, ?obj) AS ?value) .
  FILTER ( ?user = <http://Plone/author/john> )}
```

Table 1. John's personal information semantically described.

Predicate	Value
http://xmlns.com/foaf/0.1/topic_interest	Internet of things
http://xmlns.com/foaf/0.1/topic_interest	Semantic web
http://xmlns.com/foaf/0.1/topic_interest	Recommender systems
http://xmlns.com/foaf/0.1/birthday	10–29
http://xmlns.com/foaf/0.1/gender	male
http://xmlns.com/foaf/0.1/age	53
http://xmlns.com/foaf/0.1/lastName	Smith
http://xmlns.com/foaf/0.1/firstName	John

User Interactions: This query proposes to relate the participants of communities of practice according to their interactions in the same context. The query considers all users actions, including those do not result in information accessible by their peers, such as content access and search. This query implies some level of interaction between users, however, does not allow to affirm that there was

collaboration between the participants of communities of practice. Access by different users to the same resource, for example, is part of these results (Table 2), but can not be considered a collaborative action, even if users benefit from the content when accessing it.

Query 2. John's interactions with other participants.

```
SELECT DISTINCT ?context ?john_action ?user2 ?action2
WHERE {
  ?action coppla:context ?context .
  ?action coppla:agent ?user .
  ?action rdf:type ?type1 .
  ?type1 rdfs:label ?joao_action .
  ?action coppla:startTime ?datetime .
  ?context coppla:title ?context_title .
  ?other_action coppla:context ?context .
  ?other_action coppla:agent ?other_user .
  ?other_action rdf:type ?type2 .
  ?type2 rdfs:label ?action2 .
  ?other_user foaf:firstName ?user2 .
  FILTER( ?user = <http://Plone/author/joao> &&
  ?user != ?other_user )
} ORDER BY(?datetime)
```

Table 2. John's interactions with other participants.

Context	john_action	user2	action2
Collaborative Filtering	Consume Action	Rosa	Comment Action
Collaborative Filtering	Share Action	Rosa	Comment Action
Collaborative Filtering	Follow Action	Rosa	Comment Action
FOAF/SIOC Ontologies	Consume Action	Matheus	Comment Action
FOAF/SIOC Ontologies	Consume Action	Matheus	Follow Action
FOAF/SIOC Ontologies	Consume Action	Rosa	Reply Action
FOAF/SIOC Ontologies	Consume Action	Matheus	Share Action
Collaborative Filtering	Reply Action	Rosa	Comment Action
FOAF/SIOC Ontologies	Reply Action	Matheus	Comment Action
FOAF/SIOC Ontologies	Reply Action	Rosa	Reply Action
FOAF/SIOC Ontologies	Reply Action	Matheus	Share Action
OBAA Pattern	Consume Action	Clara	Comment Action
OBAA Pattern	Consume Action	José	Reply Action
OBAA Pattern	Comment Action	José	Reply Action
OBAA Pattern	Comment Action	Clara	Share Action

Communication Actions: Looking forward to identifying collaboration in communities of practice, this query attempts to relate users in contexts where more than one participant has interacted through communication actions (*CommunicateAction*), subclass of action (*Action*) on the CoPPLA ontology. This query definition allow us to follow the **collaboration trajectory** from the perspective of individual users, but also, the association with the other collaborative activities in the various contexts of a CoP, representing the collective production of the participants and the community of practice, displaying its practice and domain. In this way, the collaboration trajectory of a user is inferred from the relationships between the participants in the same content, either through sharing or discussions about the resource (Table 3).

Query 3. John's interactions with other participants.

```
SELECT DISTINCT ?context ?user1 ?action1 ?user2 ?action2
WHERE {
  ?action rdf:type ?type .
  ?type rdfs:subClassOf* coppla:CommunicateAction .
  ?action coppla:context ?context .
  ?context coppla:title ?context_title .
  ?action coppla:agent ?user .
  ?user foaf:firstName ?user1 .
  ?action rdf:type ?type1 .
  ?type1 rdfs:label ?action1 .
  ?action coppla:startTime ?datetime .
  ?other_action coppla:context ?context .
  ?other_action rdf:type ?type2 .
  ?type2 rdfs:subClassOf* coppla:CommunicateAction .
  ?other_action coppla:agent ?other_user .
  ?other_user foaf:firstName ?user2 .
  ?other_action rdf:type ?type2 .
  ?type2 rdfs:label ?action2
  FILTER( ?user = <http://Plone/author/john> &&
  ?user != ?other_user )}
```

7 Results and Discussion

This work propose a mapping of relationships among CoPs, collaboration tools, participants and their interactions, proposing a semantic representation for the dynamically constructed knowledge in CoPs. The proposed solution establishes services for the acquisition, persistence and recovery of interactions in CoPs. A semantic server stores the RDF triples described with the CoPPLA, FOAF and SIOC ontologies, allowing the execution of semantic queries and inferences. These queries retrieve information from the users and their dispersed interactions in the various collaboration tools of a CoP. This information can be used to find interests, historical interactions, and collaboration trajectories in CoPs.

Table 3. Example of John's collaboration trajectory.

Context	user_1	type_action_1	user_2	type_action_2
Collaborative Filtering	John	Share	Rosa	Comment
Collaborative Filtering	John	Reply	Rosa	Comment
FOAF/SIOC Ontologies	John	Reply	Matheus	Comment
FOAF/SIOC Ontologies	John	Reply	Rosa	Reply
FOAF/SIOC Ontologies	John	Reply	Matheus	Share
OBAA Pattern	John	Comment	Clara	Comment
OBAA Pattern	John	Comment	Clara	Share
OBAA Pattern	John	Comment	Jose	Reply

The first contribution of this work was the adequacy of ontologies and the use of semantic web technologies to formalize the environment information. From the CoPs knowledge formalization, the information interoperability was improved and semantic queries and automatic processing became possible to be performed. The user profile with associated semantics is able to store information that was previously scattered among different CoP collaboration tools. The ability to track user interactions, capturing different aspects of their interactions, and representing them with semantic value allows to combine, reuse, and share the knowledge dynamically constructed during exchanges between participants.

Semantic queries have the ability to retrieve information related to the static and dynamic aspects of the participants. The proposed representation is capable of organize information that is linked to both the user and their relationship network. Thus, the dynamic profile is updated according to the user's actions and with their colleagues actions. To these actions it is possible to associate the context and the moment in which they occurred, the participants involved, the type of action executed and the collaboration tools used. These information, organized from an individual perspective, allows the retrieval of **interaction histories and collaboration trajectories**. This may be explored to understand how knowledge is built on CoPs and allows the construction of new collaboration tools based on the behavior pattern of each participant.

Future work intends to evolve the user profile and aspects related to the performance, security and privacy of semantic queries. The use of the semantic web also allows the execution of federated queries that can access resource descriptions on external semantic bases. Thereby, it is possible to search for new relationships and combine information to generate new knowledge. Finally, the organization of the user actions in a formal representation allows the execution of complex queries, retrieving and combining information, including incomplete ones, to discover new knowledge. From this information, it is possible to create interactive dashboards combining user actions, contexts, other participants who interacted in the same resource, related materials and related topics. The

dynamic user profile evolves as the interactions occur in the CoPs and may be explored to adapt the platform and to improve recommendation systems.

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