A Collaborative Working Environment as an ontology-based collaborative System of Information Systems

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***Abstract*—Integrating various collaborative tools, a web-based Collaborative Working Environment can support collaborations between users. In collaborative processes, many resources are produced and stored distributively within these tools. This raises an issue: how to organize these resources in a Collaborative Working Environment. In our research, we intend to consider a Collaborative Working Environment as an ontology-based collaborative System of Information Systems and apply a collaboration context ontology for managing resources and generating resource recommendations to users. In this paper, we present a prototype of such environments and show how it can be used.**

***Keywords*—Collaborative Working Environment, System of Information Systems, Ontology, Collaboration context.**

I. Introduction

With the developments of information technologies, many collaborative tools are provided to users, such as e-mail and real-time chat tools [1] [2]. They can be integrated into a web-based Collaborative Working Environment [3]. Such environments enable users to collaborate beyond the limit of geographical distances and make collaborative work in companies more agile and flexible. While collaborating, users typically need to utilize different tools and generate various resources (e.g., documents and videos) within them. The access to such resources, which are distributed across separate tools, is a barrier to efficient collaboration. Therefore, one of the current issues is how to organize these resources through centralized access in a Collaborative Working Environment.

In Collaborative Working Environments, the resources are stored in different collaborative tools that are autonomous information systems, based on the definition of information system [4]. Thus, these systems, together with the environment itself can form a System of Information Systems [5]. With the different resource managements in such systems [6] [7], we intend to build a Collaborative Working Environment as an ontology-based collaborative System of Information Systems, so that each resource can be managed in an ontological knowledge base [5] and stored in the information system where it was produced.

However, these resources are produced and/or used to achieve the goals of collaboration [8]. Both resources and goals are affected by a context of collaboration [9], which is worth specifying to make the collaboration more efficient. This requires us to consider the collaboration context within the ontological knowledge base. Thus, we implement a collaboration context ontology to manage resources in a Collaborative Working Environment. In doing so, different resources can be indexed and organized by the shared vocabularies defined for collaboration goals.

The remainder of this paper is constructed as follows. Section II studies Collaborative Working Environments and Systems of Information Systems. Section III presents our contributions in (i) adapting an architecture of an ontology-based collaborative System of Information Systems, (ii) applying a collaboration context ontology, (iii) developing a Collaborative Working Environment prototype based on the architecture and the collaboration context ontology. We then discuss the strengths and weaknesses of the prototype. Finally, some conclusions and future work are shown in Section V.

II. Related work

This section introduces Collaborative Working Environments and discusses their functions. Another notion System of Information Systems is also investigated.

A. Collaborative Working Environment

With a common goal to achieve [8], a collaboration involves two or more persons and comprises a set of human actors' actions on behalf of the corresponding collaborator [10]. Nowadays, more and more people are collaborating remotely with the help of various technologies, such as Web/Internet, Information and Communication Technology (ICT), and technologies in the Computer Supported Collaborative Work (CSCW) field [3] [11]. This leads to the emergence of a new collaborative space, a **Collaborative Working Environment (CWE)** where users can work together as spontaneous and dynamic groups assembled in a collaborative manner [12].

CWEs, especially web-based CWEs, support e-collaborations between users in groups [13]. Each group has a space accessible to its members (users) [14]. This allows all members of a group to work in a shared space within the group [13]. Besides, different groupware applications can be integrated into CWEs as collaborative tools [3] to support users' actions by groups. By gluing these tools, CWEs empower users to collaborate in multiple groups at the same time. Other tools powered by ICT are available in CWEs, such as email and document sharing tools [2] [13] [15].

Based on [3] [11] [12] [13], CWEs offer functionalities to: 1) Allow users to collaborate over time and space; 2) Support users' various activities during their collaborations, such as interactions with other users and/or resources; 3) Integrate and offer different collaborative tools: both asynchronous[1] (e.g., email and Wiki) and synchronous[2] (e.g., real-time chat and video communication systems); 4) Provide flexible services for users to support their collaborations; 5) Enable interoperability among different collaborative tools; 6) Increase the productivity and creativity in collaborative processes; 7) Enhance users' critical thinking, analytical thinking, and problem-solving skills.

Many research already developed CWEs for different domains. For example, Su and Casamayor [11] applied a CWE to enhance sustainable furniture design. Truong et al. [15] aggregated multiple collaborative tools into a CWE for team collaborations. Among these existing CWEs, there is a common and unresolved difficulty: switching from one collaborative tool to another imposes a resource (e.g., documents, figures) burden on users [16]. When users shift between collaborations or perform multiple activities, they must copy and/or move resources between these tools. Particularly, such resources are stored in different databases, either in the tools where they were produced or in the CWE itself. This complicates both resource access and management in a CWE. Accordingly, it also raises challenges to how collaborative tools can be integrated into a CWE [12].

Thus, we need to organize resources with centralized access in a CWE. For this, we have to improve the manner in which collaborative tools are integrated into a CWE. Each tool is an autonomous information system with its own database. Together with the CWE, they can form a System of Information Systems (SoIS) [5]. To understand the relation between CWE and SoIS, SoIS should also be analyzed.

B. Systems of Information Systems

The notion System of Information Systems (SoIS) is conceptually originated from that of **System of Systems (SoS)**. A SoS is a new type of system that is formed by the collaboration between its components, which are themselves independent systems [17]. This implies that there are two parts in a SoS: the *global system*, which is the collection of its components, and the *component systems*, which are independent and heterogeneous systems [17]. As for a CWE, its integrated collaborative tools are the component systems, while the CWE itself is the global system.

Regarding the different management and relations between the global system and the component systems, a SoS can be classified into four categories [6] [7]: 1) **Directed SoS** is built to fulfill specific purposes and centrally managed (e.g., the systems responsible of the development of the Future Combat Systems in the US Department of Defense [7]); 2) **Acknowledged SoS** has central management and common resources. Nevertheless, component systems retain their independent ownership and purposes. Changes in the SoS are based on the collaboration between the SoS and the component systems (e.g., Air Operation Center [7]); 3) **Collaborative SoS** does not have central management with coercive power. Component systems collaborate to fulfill the central purposes (e.g., the Internet [6] [7]); 4) **Virtual SoS** lacks both central management and centrally agreed common purposes. It emerges from the interaction between its components, whereas the purposes are unknown. This SoS is maintained through invisible mechanisms (e.g., World Wide Web [6]).

Particularly, if every component system in a SoS is an information system, this SoS is a SoIS [5]. Here, an information system contains a set of interrelated components performing activities for collecting, processing, storing and distributing information, while a system is a set of elements dynamically interrelated to perform activities aiming at achieving a specific goal [4]. As a special SoS concerning information, SoIS can also be placed in the four categories. For instance, the Internet is a collaborative SoIS that comprises different information systems for providing diverse information services to people (see Fig. 1).

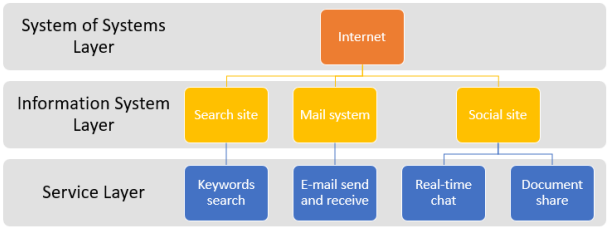

Fig. 1. Internet is a collaborative SoIS.

Specifically, each collaborative tool integrated into a CWE is an independent and autonomous information system with its own database and management. Thus, a CWE can be considered as a SoIS. This implies that a CWE can also be divided into the four categories of SoIS. For instance, the CWE created by Su and Casamayor [11] is acknowledged. Because it has central management and common resources. However, accessing and managing common resources in acknowledged CWEs create a barrier for people (cf. Section II-A).

To organize resources distributed across information systems in a CWE, a CWE can be considered as a collaborative SoIS with central resource management. This is because no common resources exist in such a CWE. Instead, each resource is private for the information system where it was generated.

[1]Asynchronous collaborative tools let users collaborate at distinct times [1].
[2]Synchronous collaborative tools let users collaborate at the same time [2].

All resources are visible, accessible and centrally managed within the CWE. Notably, an ontology-based collaborative SoIS, which can manage information across separate systems, was developed [5]. Considering the relation between CWEs and collaborative SoISs, we thus decide to implement a CWE as an ontology-based collaborative SoIS.

III. Contributions

This section explains how to build a Collaborative Working Environment (CWE) by adapting an architecture of an ontology-based collaborative System of Information Systems (SoIS) and applying a collaboration context ontology. In doing so, a corresponding prototype of CWE can be developed, which centrally manages the resources distributed in different tools. Finally, the prototype is presented in supporting collaborations and generating resource recommendations to users.

A. An architecture of Collaborative Working Environments

Saleh and Abel [5] proposed a leader-follower architecture of collaborative SoISs (see Part (a) in Fig. 2). In this architecture, a collaborative SoIS is composed of a leader system that refers to the global system and multiple follower systems that are component systems. Particularly, the global system contains an ontological knowledge base to collectively manage information across different information systems.

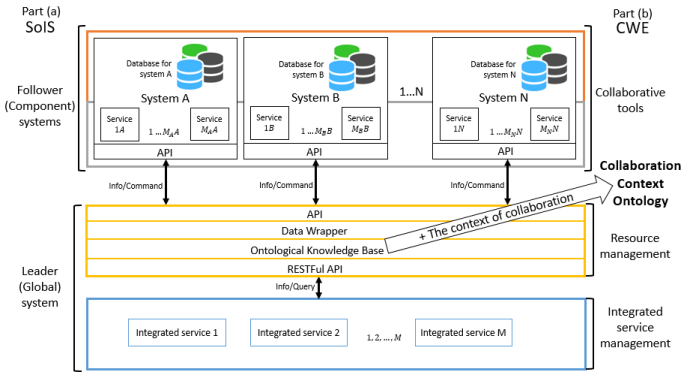

Fig. 2. Considering a CWE as an ontology-based collaborative SoIS.

Considering a CWE as an ontology-based collaborative SoIS, this leader-follower architecture can also serve as an architecture of CWEs (see Part (b) in Fig. 2). Specifically, the component systems are collaborative tools providing their own services (e.g., service 1A, ..., $M_A A$ in Fig. 2), and the global system indicates a CWE with integrated services (e.g., integrated service 1, ..., M in Fig. 2). Collaborative tools are added in a CWE to offer and integrate their services into the CWE, thus supporting collaborations. When they are not desired, they can also be removed from a CWE by disconnecting with the CWE. Besides, four parts in the CWE can manage resources: *API*, *data wrapper*, *ontological knowledge base*, and *RESTFul API*. *API* exchanges information of resources with collaborative tools. Then, *data wrappers* aims to manage the collected information and store it in an *ontological knowledge base*. Finally, *RESTFul API* offers uniform interfaces to access and manipulate resources [18]. Such an architecture (see Part (b) in Fig. 2) allows resources located in independent tools to be visible and accessible in CWEs without modifying their storage location (source).

Considering that collaborations are goal-oriented [8] [10], resources are produced and/or used to attain common goals of collaboration. Hence, resources should be managed with respect to the collaboration goals in the CWEs. However, both resources and goals can be influenced by the context of collaboration, such as collaborators' activities [9]. This requires us to consider the collaboration context within the ontological knowledge base for managing resources. Thus, a collaboration context ontology [9] is implemented as the knowledge base in the architecture of CWEs (see Part (b) in Fig. 2). Such architecture leads to building a CWE prototype where resources are managed within the collaboration context.

B. A collaboration context ontology

The collaboration context ontology **MEMORAe-Collaboration-Context (MCC)** [9] employs a concept of user group, mcc:UserGroup (see Fig. 3), to represent collaborations. Surrounding this concept, eight dimensions of the collaboration context are represented by different concepts and/or their interrelationships, including: Goal, Collaborator, Activity, Resource, Time, Location, Relation, and Satisfaction [9]. A mcc:UserGroup is established for a time period, has a goal and provides a group space accessible to its members (at least two) with their user accounts.

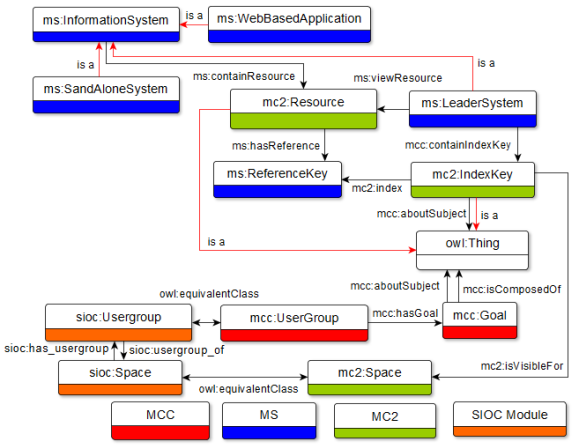

Fig. 3. Resource module in MCC [9].

In group spaces, users can access and consult the resources distributed in different tools through their user accounts. As shown in Fig. 3, resources are contained in the database where they were originally stored, either in a CWE (represented by ms:LeaderSystem) or in a collaborative tool (represented by ms:WebBasedApplication and ms:SandAloneSystem) integrated into the CWE. To associate the resources in collaborative tools with the CWE, ms:ReferenceKey is applied. Each ms:ReferenceKey is included in the CWE and has a mc2:IndexKey that is visible to certain group spaces. This

binds resources with user groups. Through mc2:IndexKey and ms:ReferenceKey, all resources are accessible and visible in user groups of the CWE. When users performing different activities about resources (e.g. sharing, voting and deleting resources), it is their reference keys and index keys that are used and modified, rather than themselves in the databases.

Besides, mcc:Goal (see Fig. 3) represents the goal of collaboration. Since collaborations are relevant to each other within a company or organization, an organizational knowledge graph is applied to define a shared vocabulary describing collaboration goals. Each node in knowledge graphs is a useful concept for collaboration goals in an organization, represented by owl:Thing (see Fig. 3). Meanwhile, each mc2:IndexKey is linked to owl:Thing. This signifies that resources in the CWE are tied to the collaboration goals through MCC.

Applying MCC as the ontological knowledge base permits resources to be indexed and managed with shared vocabularies of collaboration goals. This helps to determine the utility of resources and thus generate resource recommendations to users for facilitating their collaborations in CWEs.

C. Prototype

Based on the architecture of CWE (cf. Section III-A) and the collaboration context ontology (cf. Section III-B), a CWE prototype is developed: **MEMORAe CWE**. This section explains how MEMORAe CWE can be used to organize and recommend resources to users, based on a collaborative work scenario in companies.

a) A collaborative work scenario: FileX company aims to develop various applications of file editors and translators. Currently, this company is concentrating on two applications: a web application and an Android application of a file editor. The two applications are respectively carried out by two groups. Specifically, Lucie, Mary and Steve are collaborating on the web application. Lucie, Emma and Leo work together for the Android application. Besides, the desktop application of the file editor was produced by Lucie, Majd and Nathalie.

b) MEMORAe CWE: In MEMORAe CWE, users have access to various organizations. Once an organization is selected, users can browse a corresponding knowledge graph of that organization. In such a graph, each node, with its own description, represents a concept about the collaboration goals within the organization. In the scenario, FileX company defines concepts about its collaboration goals and maps them in a knowledge graph. All FileX employees can consult the graph in MEMORAe CWE (see Fig. 4).

Each organization includes one or more user groups whose members collaborate with each other to achieve a common goal. In the scenario, the two groups for developing different applications are two user groups in MEMORAe CWE. Their goals are to develop the corresponding application of the file editor. Particularly, each user group provides a space that enables its members to interact with resources distributed in different collaborative tools. In the scenario, Lucie shared with Mary and Steve a web link to a Youtube video about file editors in the group space. Here, the web link is a resource that is stored in Youtube but accessible and visible in a user group of MEMORAe CWE (see Fig. 4). Except web link, a resource can also be a document, an annotation, a vote, a comment, or a geographical location.

Specifically, all resources in MEMORAe CWE are indexed with nodes in knowledge graphs[3] by users. In the scenario, the web link shared by Lucie is indexed and visible with the node *File editor*. Nodes in a knowledge graph define a shared vocabulary used by collaborators to describe collaboration goals. Notably, resources are visible and accessible only with the indexed nodes. This assists users in organizing resources around collaboration goals. Moreover, since a knowledge graph is shared within an organization, all members of an organization's user groups can index resources in the same graph. This permits users to understand and visualize indexed resource in an organization from a single graph. When Lucie selects the node *File editor* in MEMORAe CWE, she can view all indexed resources within her two user groups (see Fig. 4), and differentiate between resources in separate groups.

MEMORAe CWE can integrate collaborative tools for enabling users to conduct diverse activities on resources. These tools are found under *Accessible Systems* menu in Fig. 4. The activities are traced by user groups. In the scenario, Lucie's activities in the user group of the Android application are shown in Fig. 5. Such traces can be viewed by activity type (see Fig. 5), resource type, resource name, index (concept) name, date, and actor (user). Using these traces, resource recommendations can be generated for users.

Considering that the indexed resources and the relevant concepts (indexes) are two sets in a user group, the user group c can be represented as a union of these two sets $R^c \cup S^c$. $R^c = \left\{r_j^c | j \leq N_r^c, j \in N^+\right\}$ is the set of all indexed resources in the user group c; N_r^c is the number of such resources in the user group c; $S^c = \{s_k^c | k \leq N_s^c, k \in N^+\}$ is the set of all relevant concepts that index resources in the user group c; N_s^c is the number of such concepts in the user group c.

Then the resource recommendation problem in MEMORAe CWE is formulated as: given a concept s and a user u in a user group c with two sets of resources R^c and concepts S^c, the top K resources $i (i \notin R^c)$ that can be indexed with the concept s in the user group c with the highest probabilities will be recommended to u for facilitating u's collaboration in the group c. The steps to generate recommendations[4] are:

1. Calculate similarity $S(c_i, c)(i = 1, 2, ..., N-1)$ between resource sets in the user group c and other user groups $c_i (c_i \neq c)$ on a shared knowledge graph. Here, N is the number of user groups that the user u is a member of.
2. Rank user groups c_i based on $S(c_i, c)$ in decreasing order.
3. Filter out irrelevant resources $i (i \notin R^c)$ that are not involved in c_i with the K highest $S(c_i, c)$ or not indexed with the concept s, and get relevant resources i'.

[3]A node in knowledge graphs is a concept or an index with which resources can be indexed.

[4]Notably, $rating(u, i')$ is given based on the users' voting activities on the resource i', which belongs to the range $[0, 5]$. In this paper, we do not discuss how it is calculated.

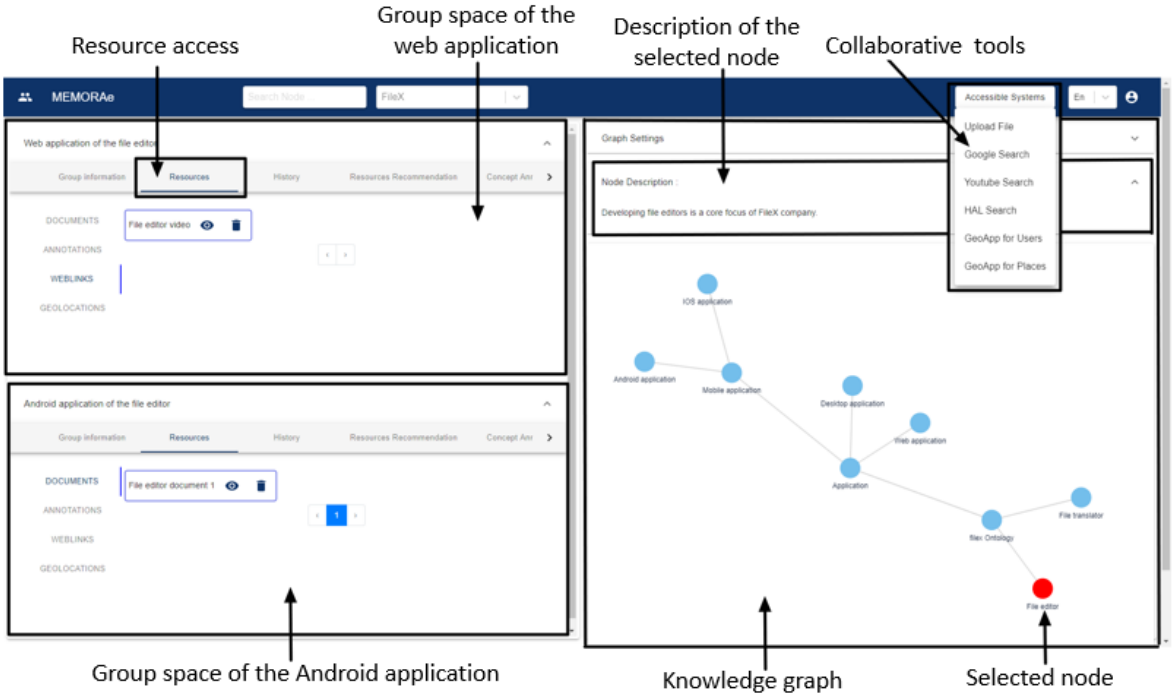

Fig. 4. Lucie's interface in MEMORAe CWE.

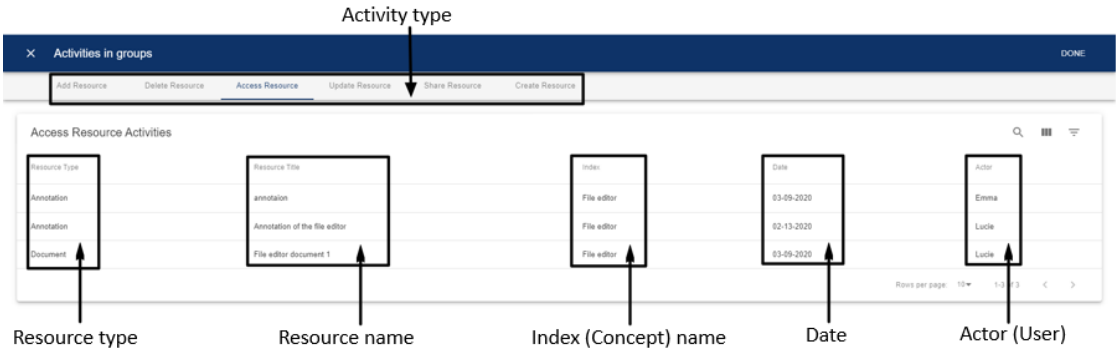

Fig. 5. Lucie's activities in the user group of the Android application.

4. Recommend/Return the resources with the K highest $rating(u, i')$ to the user u in the user group c.

To calculate the similarity between two resource sets in user groups, we need to measure common resources. Based on [19] [20], such similarity between the user group c and another user group x is:

$$S(x,c) = \sum_{a=1}^{M} \frac{|R^x_{s_a} \cap R^c_{s_a}| \times Weight(s_a)}{|R^x_{s_a} \cap R^c_{s_a}| + \alpha|R^x_{s_a} - R^c_{s_a}| + \beta|R^c_{s_a} - R^x_{s_a}|} \quad (1)$$

where $M = |S^x \cap S^c|$ is the number of concepts that resources are indexed with in both user groups x and c; $R^c_{s_a}$ is a set of all the resources indexed with the concept s_a in the user group c; $R^x_{s_a} - R^c_{s_a}$ is the relative complement of $R^c_{s_a}$ in $R^x_{s_a}$; $|R^x_{s_a} \cap R^c_{s_a}|$ is the number of common resources indexed with the concept s_a in user groups x and c; $Weight(s_a)$ is the significance of the concept $s_a (a = 1, 2, ..., M)$; $\alpha, \beta \geq 0$.

Besides, the value of K in the steps is specified by the user u's needs. In the scenario, we consider $K = 1$ to illustrate how a resource can be recommended to the user u for the concept s. In the scenario, Lucie can receive a resource recommendation on the concept *File editor* in the user group of the web application. The user u is Lucie; the concept s is *File editor*; the user group of the web application is c; c_1 and c_2 are user groups of the desktop and the Android application. Specifically, the resources in c and c_2 are only indexed with the concept s. We have $R^c = \{"File\ editor\ video"\}$ and R^{c_2} containing *"File editor document 1"* and *"Annotation of the file editor"*. As for c_1, $R^{c_1}_s$ includes *"File editor video"*, *"File editor document 1"*, and *"Comments for the file editor"*.

Following the steps, we need to calculate $S(c_1, c)$ and

$S(c_2, c)$. Suppose that $Weight(s) = 1$ and $\alpha = \beta = 1$, so the range of $S(x, c)$ is $[0, 1]$. With the given ratings in $[0, 5]$, we know $rating(u, "File\ editor\ document\ 1") = 4.7$ and $rating(u, "Comments\ for\ the\ file\ editor") = 3.8$. Then we can get $S(c_1, c) = \frac{1\times1}{1+2+0} + 0 = \frac{1}{3} \approx 0.333$ and $S(c_2, c) = \frac{0\times1}{0+2+1} + 0 = 0$. $S(c_1, c) > S(c_2, c)$ indicates that c_1 has more common resources indexed with the concept *File editor*. In other words, c_1 is more similar to c than c_2. Next, the resources that we can recommend to Lucie are *"File editor document 1"* and *"Comments for the file editor"*. Because *"File editor video"* is already indexed in c. Besides, *"Annotation of the file editor"* is filtered out because it does not exist in c_1 with $S(c_1, c)$ that is the highest value in the similarities. Finally, the higher value, $rating(u, "File\ editor\ document\ 1")$, implies that *"File editor document 1"* should be recommended to Lucie.

Using MEMORAe CWE, users are able to collaborate with others through user groups. Within each group, resources are centrally accessible and organized by a knowledge graph that defines a shared vocabulary of collaboration goals. This helps to generate resource recommendations to users for facilitating their collaborations.

IV. Discussion

Considering a CWE as an ontology-based collaborative SoIS can improve the integration of different collaborative tools. This also allows access to resources distributed in separate tools. Therefore, resources are directly accessible components [18] in such a CWE. To test and evaluate such a CWE, MEMORAe CWE will be used to support students' collaborations in their courses at the University of Technology of Compiègne (UTC). Besides, using the collaboration context ontology [9], resources in CWEs can be organized and indexed with shared vocabularies that are used to describe collaboration goals. Particularly, users can also annotate and vote for these resources while collaborating in a user group. These annotations and votes are stored in the CWE and accessible to the members of the user group. This provides contextual information of collaborations to users so that they can adapt accordingly to better collaborate with other members in the user group. Joint indexing of resources and collaboration goals assists in generating resource recommendations to users.

V. Conclusion and future work

In this paper, we focus on how to access and organize resources in a Collaborative Working Environment (CWE). To solve this issue, we develop a CWE prototype by adapting an architecture of an ontology-based collaborative System of Information Systems (SoIS) and applying a collaboration context ontology. Based on the literature review, we justified the relation between CWE and SoIS, and explained why a CWE can be considered as an ontology-based collaborative SoIS. We investigated how a collaboration context ontology can be implemented into a CWE via the architecture of an ontology-based collaborative SoIS. The corresponding prototype was then presented. Finally, its characteristics were discussed. Our future work includes testing the recommendation algorithm and developing a corresponding recommender system as a new tool integrated into the CWEs.

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