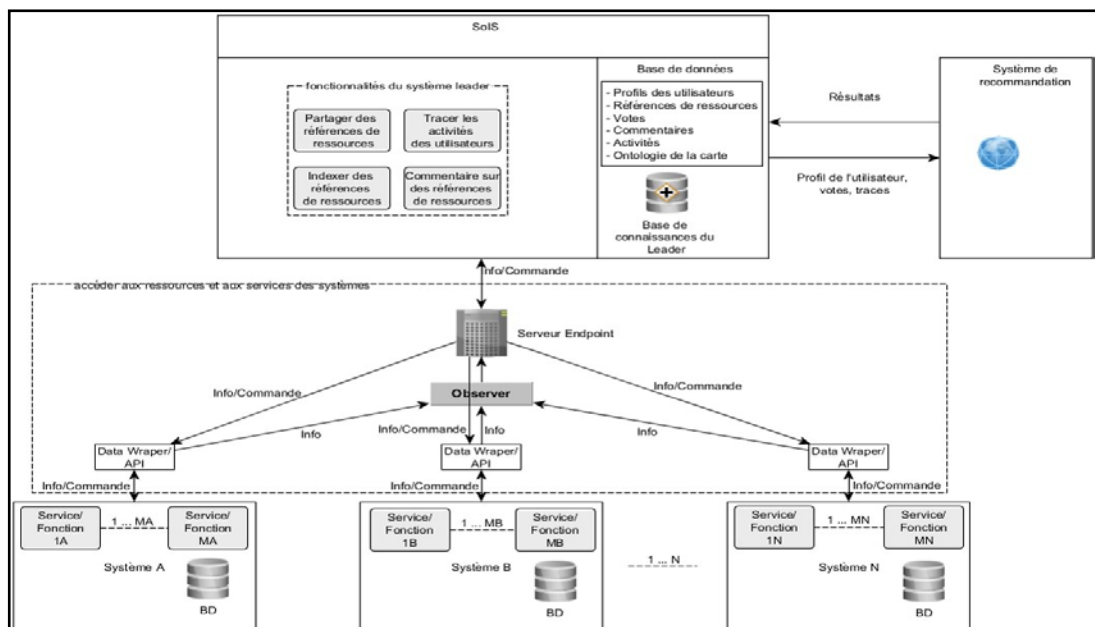


Par **Majd SALEH**

Digital ecosystem : towards a system of information systems

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Chapter 1

Introduction

Recently, with the rapid technological advancement that we are witnessing, many Information Systems (ISs), in the form of software and hardware systems that support data-intensive applications [[Avison and Fitzgerald, 2003](#)], are introduced into our lives either at home or at work. The increasing number of different ISs (software, especially web-based) that we use will result in an increment in the number of digital resources that we need to work with, keep track of, organize, and share with others. That will cause growing challenges facing users of ISs, such as the need for managing huge amounts of resources. In order to find the right information at the right time to make an educated decision, users have to look for resources distributed in many ISs (emails, social networks, wiki pages, electronic notes etc.). The process of searching for resources in different ISs is costly and time-consuming, therefore it needs to be optimized [[Wilkinson et al., 2016](#)]. The emergence of System of Systems (SoS) presents the users with the potential for improving the accessibility of different ISs and providing an added value to users that was not present when ISs were working separately. A SoS is large-scale integrated systems which are heterogeneous and independently operable on their own but are networked together for a common goal. The goal, as mentioned before, might be organizing and sharing of heterogeneous resources. [[Jamshidi, 2011](#)]

This thesis focuses on SoS as a solution to the emergent challenges facing users of different ISs in a collaboration context.

This introduction will start by highlighting the social and scientific context of this thesis. The context of this research is explained with a use case scenario. Then, the problem statement is introduced. After that, our approach and contributions to solve

the scientific problems highlighted in the previous sections are previewed. Lastly, the plan of this thesis is presented.

1.1 Social Context

In recent years, the ISs designed to support activities in the fields of banking, health, transportation, space, defense, education, etc. have become increasingly larger and more complex. With the growing maturity of Digital Ecosystems (DEs), ISs have been interconnected within growing networks, yielding new capabilities and services through the combination of system functionalities [Luzeaux et al., 2013]. Furthermore, there has been an outstanding escalation in organizations use of Information and Communication Technology (ICTs), especially web-based ICTs. Today, nearly most of the viral tasks are carried out by web-based ISs. As a result, organizations depend on many ISs to produce, work with, and manage resources. In the process of working at this manner, numerous amounts of heterogeneous resources are produced. In overall view, organizations deal with huge amount of resources distributed over different ISs.

Additionally, this advancement in ICTs results in unprecedented growth in organizations reliance on partnering and various forms of collaboration using collaboration platforms [DiMario et al., 2009]. A collaboration platform is an Information Technology (IT) based Information System that create workflow of information to specific teams and members. This allows individuals to share ideas and their talents with other members so that the task can be finished both efficiently and effectively [Haag et al., 1998]. Today, it is not enough to use one ISs in the work environment. As consequence, organizations depend on many teams to carry out the necessary tasks and achieve their goals. Those teams use many ISs to execute the delegated tasks. This puts collaboration and collaboration tools in the center of any successful organization.

Collaboration is essential among members of a DE. Collaboration is achieved by using collaboration platforms. The purpose of a collaboration platform is to support a group of two or more individuals to accomplish a common goal or objective they have set themselves [Lomas et al., 2008]. Nowadays complex and web-based collaborative platform like Google Drive or SharePoint integrated in an agile work environment make us more efficient [McAfee, 2009]. To obtain the most value from collaborators, we need to capitalize the knowledge they produce in form of heterogeneous resources scattered

in various ISs. Thus ensuring quick and organized access to these resources is not only necessary, but also crucial for collaboration.

As a general rule of thumb, time and effort are always in a direct proportion. The best case scenario is to break the ratio and reduce time without increasing effort. The “time” we seek to reduce is the time required to find, review, discuss, evaluate and access various resources produced from different ISs.

1.2 Scientific Context

The dependency on increasing numbers of ISs requires pooling the resources from these different systems to allow for more collaboration [Laurillard, 2006]. That creates the challenge of managing the huge amount of resources produced in the environment of a DE. In the literature, this challenge is addressed using numerous Information Systems [Xu et al., 2014], recent technologies such as web 2.0 and cloud computing [Manvi and Shyam, 2014], and knowledge management methodologies [Grace et al., 2013]. Furthermore, the issue of collaboration has semantic aspects especially collaboration over tacit knowledge which is difficult to transfer to others as contrary to explicit knowledge [Atrash, 2015]. On top of that, the DE has limitations when expanding to include new ISs. This limitation is due to the fact that a DE is designed from the start with its constituent ISs [Dong and Hussain, 2007]. The use of SoS paradigm facilitates the inclusion of new constituent ISs in the digital environment of a DE.

The goal of a DE is to maintain the performance of its constituent systems and preserve the digital environment in which those systems operate [Dong and Hussain, 2007]. The functionality of the DE however is determined by the functionalities of its constituent systems. The DE in a defense institution has different systems than the one in a university, hence it has different functionalities. The limitation of a DE is in its ability to expand and include more systems that can serve new goals and help improve its functionalities [Bharadwaj et al., 2013]. All constituent systems in a DE are designed to work in the digital environment of the DE. For example, the DE of Thales satellite has many pieces of equipment and ISs that work in harmony within the digital environment of Thales. They all have been made for the purpose to work together in this DE [Gilly et al., 2011]. Another example in a different domain is the

Adobe Creative Suite. This DE contains different ISs that allow the user to design, illustrate, and execute different multimedia products. All the different ISs in the digital environment of Adobe Creative Suite are interoperable and compatible. The components of DE are designed to work together under the condition of their environment. The limitation of DE is the lack of a pre-established methodology to incorporate new ISs in its digital environment [Gar, 2017]. The SoS approach, similarly to DE, enables users to access different systems with the ability to add new systems to the orchestration of the SoS [Fang and DeLaurentis, 2014]. The main difference between DE and SoS is that the latter has a more convenient methodology to incorporate new systems in the orchestration of SoS [Madni and Sievers, 2014].

In order to employ available solution to the favor of solving emergent problems, we need to follow the approach of SoS. This can be achieved by aggregating existing systems and providing centralized access to them. In turn, this makes innovation, flexibility, coordination, integration, and speed the new success factors of today's work environment. Those factors can be reached through the concept of SoS.

A System of Information Systems (SoIS) is a type of SoS where all the constituents systems are ISs. Within the environment of the SoIS, resources come from different ISs. These resources, if managed properly, could improve the understanding of collaborators in their field of expertise [Deparis et al., 2014]. This improvement can be achieved through establishing a common ground for collaborators to work together with the overwhelming amount of the heterogeneous resources. It is certain that different resources coming from different ISs are related to the same topic. It is considerably more efficient for users to be able to find all the resources together on the same topic. This eventually will extrapolate the problem of wasted time trying to find the right resources for the right user. It will ultimately lead to having an indexing schema where only related resources are indexed together based on a shared hierarchy of terminology.

As users we deal with many DEs on daily basis; From Cloud services to social networks. However, the current DEs face interoperability problems when communicating with each others [El Sawy and Pereira, 2013], struggle to manage overwhelming amount of resources [Weill and Woerner, 2015], and fail to keep up with the services provided by different systems (voting and commenting on resources, recommender systems, resources sharing and collaboration, etc.) [Karakas, 2009]. Using the SoIS approach that supports the previously mentioned indexing schema will allow having a heterogeneous mix of resources indexed together under a certain concept and work to complement

each other. Furthermore, this will allow for further functionalities like being able to comment on resources and vote on them to enrich the information flow in the organization. In addition, this can provide the ability to trace users' activities and eventually use this information as an input to a recommender system that can recommend useful resources under specific topics.

1.3 Problem Statement

As established in the context of this research, users have to work with heterogeneous resources collected from separate systems collectively. The struggle is with accessing all these resources in different systems. The problems reside in the time required to traverse between different systems and keep track of all the information obtained from them. There is a need for a solution that allows us to preserve the autonomous nature of different Information Systems operating within the organization, and still be able to organize, access, track and analyze the resources produced by those systems. The aim is to move towards a SoIS to manage heterogeneous information coming from different ISs and improve the process of sharing and recommending resources with simplicity and ease.

In this thesis, we address the following problems:

- How to access, share and index resources coming from different ISs with a community in order to achieve a common goal?
- How can we recommend useful resources from different ISs to users?
- How to define a DE that allows users to work with resources coming from different ISs under the objective of collaboration?

1.4 Our Approach and Contributions

In this research, we follow the approach of SoS to establish a centralized access point where a user can access, share, and index the resources coming from different ISs. Users then can work and collaborate with these resources. This will save time for the user and facilitate capitalizing resources from different projects, teams, and organizations. In

addition, the SoS approach gives the ability to provide added value to users that are not present when the ISs are working separately. This added value can be found in the form of heterogeneous resources organization (indexing and sharing) and recommendation where the SoS recommends resources from different ISs based on users' profiles, their actions in the SoS, and their target goals. The deemed SoS has a methodology for adding ISs to its environment that makes it more flexible than a DE when users decide to include new ISs in their work environment.

To reach the goal of this research several steps took place:

Modeling the SoS. The model of the SoS helps in defining how users are able to access, share, and index the resources from different ISs [Saleh et al., 2015b], [Saleh et al., 2016b], and [Saleh and Abel, 2017a]. In order to develop the model of the SoS, we extended a model for collaboration and resources management called MEMORAcore2 (mc2) model. The mc2 model employs the Semantic Web standards [Atrash et al., 2014] (SIOC, FOAF, BIBO). It has been used and proven to operate well for representing resources, users, and organizations with several studies and experiments [Atrash, 2015] [Ning, 2016].

Developing the resources recommender system. The recommender system that recommends heterogeneous resources to users is developed based on our SoS approach. It is based on our SoS model to work with resources coming from different ISs [Ameur et al., 2017b] and [Ameur et al., 2017a].

Designing the architecture of the SoS. The architectural model of the SoS presents the first concrete step in implementing the prototype. The SoS aggregates heterogeneous resources from different autonomous ISs. The architectural model shows, in details, the communication lines in the SoS. While some systems are openly providing an API for requesting their services, other systems are closed and operate as black boxes to the outer world and only provide functions invoked within the system itself. Information can be represented in different ways within different systems, thus, the SoS might face some troubles accessing information, unless the services of that system are available through an API. All these issues are addressed by the architectural model in order to have a clear view of how to define a DE as SoS that supports collaboration [Saleh et al., 2015a] and [Saleh and Abel, 2015].

In order to test the validity of our approach (comprising the semantic model, the recommender system, and the architectural model) we took the following tasks:

Implementing the prototype of the SoS. The prototype is developed based on the semantic and architectural model and it implements the resources recommender algorithm. The main functionalities of the prototype are defined from the semantic model. However, the usage of the prototype is determined by its constituent ISs. As we said before in the scientific context, the constituent systems in the SoS brings different types of resources based on their domain of application. Therefore, we can say that there are several applications of the prototype that have been implemented [Saleh and Abel, 2016b], [Saleh et al., 2016a], [Saleh et al., 2017], and [Saleh and Abel, 2017b].

Testing the prototype. One of the applications of the prototype has gone through an academic test with the students at the University of Technology of Compiègne (UTC). The goal of the test was to collect feedback from students about their experience with the prototype. The tests took place in several courses; NF01 (Algorithmic and Programming) course during spring 2017 semester [Saleh and Abel, 2017b], and the courses IA03 (Technology of Modeling, Capitalizing and Managing Knowledge), IA01 (Artificial Intelligence), AI02 (Artificial Intelligence: Knowledge representation), and AI11 (Technology of Modeling, Capitalizing and Managing Knowledge) during autumn 2017. The application of the prototype was used by 215 students divided as regular learners and students in a cooperative education mode.

1.5 Use Case Scenario

We propose the following scenario to illustrate the need for SoS:

John Doe is a college student who joins a study group composed of his peers. Ordinarily, they use web links for tutorials and useful information, University portal that contains resources about the course which can be also considered as a web link, wiki pages of certain subjects, note-taking applications, contact lists to save important contacts of their instructors and colleagues, a system to upload and share their documents with each other's and their instructors, and even social media networks sometimes to discuss about the material of the course or follow certain announcements. In general, they use many ISs to produce resources and work together with these resources. First of all, we can note that these ISs don't belong to one DE. They come from different domains and serve various purposes. Also, it is certain that different resources coming from different systems are related to the same topic. It is considerably more efficient for

students to be able to find all the resources together on the same topic. In addition, the students need to be able to collaborate and give their opinion on each others' work. They vote and exchange comments about the resources they produce.

Here is a list that represents a scenario of what happens inside the study group of John:

- John is a part of a study group with his peers to work together on a certain subject "Java Programming".
- John wants to learn Java, so he wants to see what other students in his study group use as a tutorial to learn java.
- One student in the study group shares a document "Advanced Java" with the rest of the group under the subject of "Java Programming".
- John sees the document "Advanced Java" and votes and comments about the document.
- John also wants to share a web link that he found online about java. He wants to see what his colleagues think about this weblink by checking the votes and comments of other students in his study group.
- John wants to know what are the suitable resources for him to learn java.

To help John and his colleagues, this thesis focuses on modeling and implementing a SoS that corresponds to their needs.

1.6 Plan

The rest of this thesis is organized as follows:

Chapter 2 State of the Art: This chapter is dedicated to the literature review. We start by giving some background of the concept "ecosystem" as an ecological term, and then we move from there to more domain specific terms (Business Ecosystem, Digital Ecosystem, and Learning Ecosystem). We also introduce the concept of System of Systems and focus on the type System of Information Systems (SoIS) and how they can facilitate the transition from a traditional DE to a more flexible and collaborative work

environment. Finally, in order to place our work with respect to recent technologies, we discuss the state of the art of the SoIS and the current collaborative platforms available for the users.

Chapter 3 Our Approach: In this chapter we answer the question of how to manage heterogeneous resources coming from different autonomous ISs. The aim is to move towards a SoIS to manage heterogeneous resources coming from different ISs and control the process of sharing information with simplicity and ease. To achieve this goal, we introduce a semantic model of the SoIS along with an architectural model that will help controlling the SoIS construction's complexity and evolution.

Chapter 4 SoIS Prototypes: In this chapter we present the different implementations of the SoIS based on the semantic and architectural models provided earlier. The semantic model and the architecture of the SoIS permit incorporating different ISs as long as they provide a way to communicate their resource (APIs, authentication and authorization tokens, graph services, etc.). By connecting different ISs to one SoIS we are creating and providing the users with resources coming from these different ISs. Different combination of ISs will yield different applications of the SoIS. We introduce the different applications of the prototypes of the SoIS based on the ISs comprising it. In total we will review three applications of the SoIS: Web-based information systems with open API, standalone application with closed internal server, and standalone application with server open for external requests.

Chapter 5 Testing MEMORAeSoIS application for Web-based Information Systems with open API: In this chapter we present the test that we conducted with the students at the University of Technology of Compiègne (UTC). We start by defining what is a usability test, then we move to show the test scenario and finally the test results.

Chapter 6 Conclusion, Perspectives and Future Work: In this chapter, we conclude our work and give perspectives for future work.

Chapter 7 Publications: Publications related to this work are listed in this chapter.

Chapter 2

State of the Art

2.1 Introduction

In this chapter, we explore the emergent paradigm of DE. We start by providing the background for the ecological ecosystem. From there, we move forward towards more domain-specific ecosystems; Business Ecosystem, Digital Ecosystem, and Learning Ecosystem. Then, we will show the technical limitations facing this paradigm.

With the increasing number of systems trying to join the DE of the work enthronement, which result also in an increasing number of digital resources, it would be efficient to look into a more structured approach of DE [Weill and Woerner, 2015]. A System of Systems (SoS) can be viewed as a DE with more focus on organizing the communication and information exchange among different systems. In addition, the System of Information Systems (SoIS) is a special type of SoS where all of its member systems are Information Systems (ISs). In a similar way, SoIS can be considered as DE where ISs operates in the digital environment of organizations [Saleh and Abel, 2016a].

Moving forward from DE towards a SoIS increases the urge to find a solution for the interoperability problem among different ISs. As we try to solve the problem of an increasing number of ISs by migrating from a standard DE to a more structured SoIS, we face the problem of interoperability because the SoIS needs to communicate with all these different ISs. All the information coming from the SoIS can be used as an input in a recommender system that recommends resources to users based on their usefulness.

The following part of this chapter is organized as follows: Section 2.2 will define the terms (Ecosystem, Business Ecosystem, Digital Ecosystem, and Learning Ecosystem) along with providing an overview of different models, operating implementations, and limitations. Sections 2.3 and 2.4 focus on SoS/SoIS respectively. Different definitions will be cited and discussed. A proper description of the SoS/SoIS will be adopted in this thesis based on our research interest. Also, these two sections go into details about different platforms that fall into the category of DE and can benefit from the SoS/SoIS approach. Next, section 2.5 addresses an important issue related to SoS and SoIS, which is the issue of interoperability among different ISs. This section will go through different models that can help simplify information exchange across a variety of ISs. After that, the benefits of adopting semantic web standards for modeling is reviewed in section 2.6. Then, section 2.7 discusses the recommender system and which approach is best suited to be adapted to recommend resources to users in the premise of the SoIS. Lastly, we conclude with the summary of this chapter in section 2.8.

2.2 Ecosystem: Business, Digital and Learning Ecosystems

This section concerns the development of a scientific concept – the ecosystem. Metaphorically speaking, its development has a life history. There was an exact moment of birth: when the English ecologist Arthur Tansley created the word and presented it in a technical paper [Tansley, 1935]. Seven years later the term was applied in one of the most significant studies in modern ecology, the study of the trophic dynamics of Cedar Bog Lake, Minnesota, by Raymond Lindeman [Lindeman, 1942]. The Lindeman work ushered in a period of growing interest in ecosystem studies. In the discourse of this research, our view of the ecosystem is based on the abstract definition that an ecosystem is classified by biotic and abiotic components and all their interrelationships in specified physical boundaries [De Groot et al., 2002].

2.2.1 Business Ecosystem

The concept of Business Ecosystem stems from the metaphor of the ecological ecosystem introduced by Tansley in 1935. It has been transposed into economics by Moore

[Moore, 1996] and is now used in academic research in economics, sociology, and management, and in real-life managerial language as well. The concept of Business Ecosystem elaborates on networks, communities, and platforms. [Moore, 1996] defines Business Ecosystem and the idea behind the adoption of the term “ecosystem” as follows: “The term [ecosystem] circumscribes the microeconomics of intense coevolution coalescing around innovative ideas. Business Ecosystems span a variety of industries. The companies within them coevolve capabilities around innovation and work cooperatively and competitively to support new products, satisfy customers’ needs and incorporate the next round of innovation.” For [Iansiti and Levien, 2004] a Business Ecosystem is a loose network of suppliers, distributors, outsourcing firms, market of related products or services, technology providers, and a host of other organization. All of them affect and are affected by the creation and delivery of companies own offerings. According to [Iansiti and Levien, 2004] also, these entities share the fate of the network as a whole, regardless of the members’ apparent strength.

2.2.2 Digital Ecosystem (DE)

The concept of Digital Ecosystem (DE) itself was adopted from the concept of Business Ecosystem. The goal of DEs is to improve the efficiency of the communication between internal systems and to structuralize the existing Business Ecosystem. Because the research on DE is still in the beginning stage, some basic concepts are in debate. That is why it is important to go through different definitions of DE to eliminate the ambiguity that comes with it. There are two major opinions when it comes to defining DE. One is defined from the structural and functional perspective, which sees Digital Ecosystem as an open-source network environment for business mainly including small and medium enterprises to interact with others in an effective and efficient way [Ferronato, 2004]. Another one is defined by Digital Ecosystem and Business Intelligence Institute (DEBII) from the perspective of specialization, which sees it as “an open, loosely coupled, domain clustered, demand-driven, self-organizing, and agent-based environment which each species is proactive and responsive for its own benefit and profit” [Chang and West, 2006]. The former definition and related theories focus on the introduction and implementation of the DE architecture from pure technical aspect. By constructing the digital environment by means of network technology, BML (Business Modeling Languages), SDL (Service Description Languages), ontology etc., DE is attentive to the organization in which it operates, and realizes its

resources creation, tasks execution, and functions optimization [Ferronato, 2004]. The latter definition and based theories concentrate on defining the existing concepts and network architecture and swarm intelligence in DE, which tends to conceptualize and structuralize its components. Thus, the former definition is preferable to the actual implementation and commercialization, and the latter definition more inclines to the conceptualization.

A DE has been designed from the beginning to include a certain set of systems working under the umbrella of a digital environment. By the definition, these systems will work collaboratively and cooperatively to ensure the wellbeing of the DE and its environment, and to provide value to users. The limitation is when we try to expand the DE to include new constituent systems. That is why the topic of expanding DE has caught attention in the literature. The diffusion of innovations and adoption of new systems have been extensively explored. [Bass, 1969] introduced a model for the adoption of new products in terms of innovative and imitative behavior. [Dewar and Dutton, 1986] empirically tested whether different models are needed to predict the adoption of radical innovations and incremental innovations. [Loch and Huberman, 1999] introduce a punctuated-equilibrium model of technology diffusion that incorporates evolutionary aspects of technological change. [Bass and Bass, 2001] and [Bass and Bass, 2004] go on to discuss the diffusion of technology generations in the context of quickly evolving Information Technology (IT) products. Their research considers “IT waves” and models the impact of multiple technology generations on consumer adoption. A key point to expanding a DE to new system is to have the new systems designed and implemented to work within the DE. This is not always the case. That is why we need the SoS approach as it takes into consideration the inclusion of new system not intended to work within a digital ecosystem in the first place.

2.2.3 Learning Ecosystem

Learning Ecosystem fulfill the need to achieve a domain-independent solution to the problem of resources and knowledge management in complex digital environments. It aims to provide a solution that crosses the boundaries between domains and can be applied by organizations, learning institutions, and individuals. Based on the abstract definition mentioned earlier by [De Groot et al., 2002] and according to [Chang and Guetl, 2007], the Learning Ecosystem “*consists of the stakeholders incorporating the*

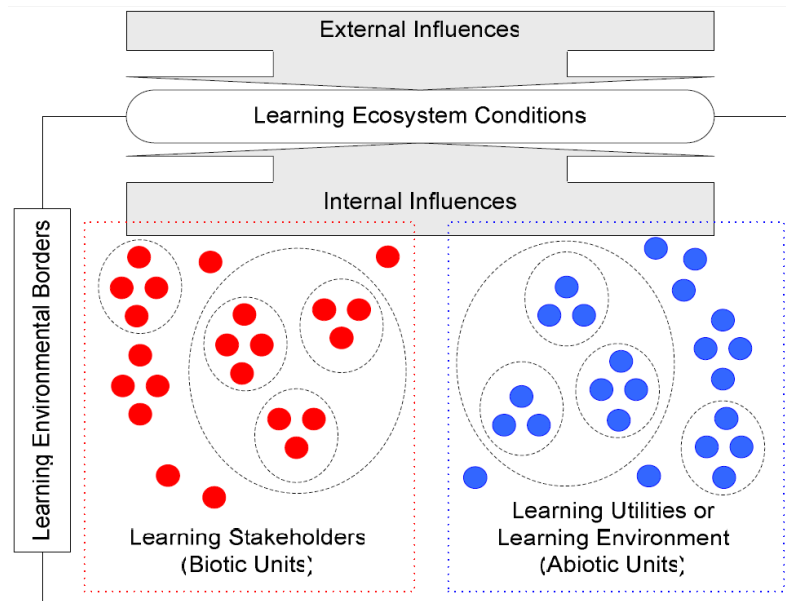


FIGURE 2.1: Simplified representation for the learning ecosystem [Chang and Guetl, 2007]

whole chain of the learning process and the learning utilities, the learning environment, within specific boundaries, which we call learning environmental borders”. According to [Davies et al., 2013], a learning ecosystem was formed by different communities interacting within and between individuals and groups, other key aspects (environment as well as tools and artifacts) are addressed implicitly.

Given the abstract definition stated above, a generic model for learning situations is outlined as follows, see also (Fig. 2.1). The learning communities and other stakeholders such as teachers, tutors, content providers, instructional designers and pedagogical experts, form the living parts of the Learning Ecosystem and are considered as the biotic units in the ecosystem. The learning utilities comparable to the abiotic units (or the learning environment comparable to the physical environment) represent the non-living parts, which include the learning media (content and pedagogical aspects), technology, and tools applied in traditional teaching methods. The learning environmental boundaries, an analogy to the specified physical boundaries of the ecosystem defines the physical and logical borders of the learning system. That is one of the system’s characteristics, which are in common specified as the learning ecosystem conditions. These conditions are determined by external and internal influences, such as the evolution of knowledge, educational goals, learning tasks, cultural and sociological aspects, and expectations by society, private industry and business organizations, the government, public service and not-for-profit organizations. Finally, in order to define

a concrete model according to [Pickett and Cadenasso, 2002], the temporal extent and the temporal and spatial scale of the system has to be specified.

2.2.4 Limitations of the Digital Ecosystem Paradigm

Users can view the DE as a center of technical supply and demand. If one DE constitutes the whole support for an organization, it is likely to be shortsighted [Bharadwaj et al., 2013]. A more comprehensive and useful approach might take a more distributed perspective on DE, one that enables numerous systems that would have been impossible under the traditional DE [Briscoe, 2010].

It's one thing if an organization possesses superior DE technology, Google Compute engine for example, but it's another thing if the organization makes that technology available to other systems. In the first case, the technology's value is limited to whatever mechanisms the organization already possesses to interact with end users. In the second case, the organization can tap other DE such as Amazon cloud service and Microsoft 365 to make its infrastructure more ubiquitous and valuable.

According to the 2017 Gartner CIO Agenda Report [Gar, 2017], CIOs (Chief Information Officer) need to prepare their organizations for digital interdependence. The DE should adapt to sharing resources with systems that reside outside of its scope.

We can summarize the limitations facing DE with the following three points:

- The inability to add an already existing system to the DE unless it is designed to work in its digital environment.
- The lack of communication interface to allow for interactions between different DEs.
- There is no methodology to organize the resources produced by different systems in the DE.

2.3 System of Systems

2.3.1 Definition

The notion of System of Systems (SoS) can be viewed as an evolution of the standard notion of systems. Many definitions of a SoS exist. An aggregate of systems leads to the creation of new forms of systems which may be either described within the framework of composite systems or demonstrate additional features which add complexity to the description and may be referred to as System of Systems.

In this section, we aim to provide abstract and generic definitions of terminology involved in the domain of systems to lead up to the definition of System of Systems.

As mentioned by [Karcianas and Hessami, 2010] “A system is an interconnected organization of objects which are embedded in a given environment”. An object is defined as “a general unit (abstract or physical) defined in terms of its attributes and the possible relations between them”. Furthermore, these objects are embedded in an environment. For a given object, we define its environment as the “set of objects, signals, events, structures, which are considered topologically external to the object, and are linked to the object in terms of a structure, relations between their attributes”. Briefly, a system can be defined as a relationship mapped over a set of objects in an encompassing environment [Simpson and Dagli, 2008]. These definitions describe how we view the internal structure and the external surrounding of a system. It is very important to agree on system’s definition before we continue to define a System of Systems (SoS), as systems represent the building blocks of any SoS.

We can summarize the definitions mentioned in literature as the following:

Definition (i): Systems of Systems exist when there is a presence of a majority of the following five characteristics: operational independence, managerial independence, geographic distribution, emergent behavior, and evolutionary development [Jamshidi, 2011].

Definition (ii): Systems of Systems are large-scale concurrent and distributed systems that are comprised of complex systems [Jamshidi, 2011] [Carlock and Fenton, 2001].

Definition (iii): Enterprise Systems of Systems Engineering is focused on coupling traditional systems engineering activities with enterprise activities of strategic planning and investment analysis [Carlock and Fenton, 2001].

Definition (iv): System of Systems Integration is a method to pursue development, integration, interoperability, and optimization of systems to enhance performance in future battlefield scenarios [Carlock and Fenton, 2001].

Definition (v): System of systems is a collection of task-oriented or dedicated systems that pool their resources and capabilities together to obtain a new, more complex, 'meta-system' which offers more functionality and performance than simply the sum of the constituent systems [Manthorpe, 1996].

Definition (vi): System of systems is a set of different elements connected or related so as to perform a unique function not performable by the elements alone [Rechtin and Maier, 2000].

In the light of the aforementioned definitions, we can describe the notion of System of Systems (SoS) as the following: Systems of systems are large-scale integrated systems which are heterogeneous and independently operable on their own but are networked together for a common goal. The goal, as mentioned before, might be cost, performance, robustness, etc. A SoS brings together a set of systems for a task that none of the systems can accomplish on its own. Each constituent system keeps its own management, goals, and resources while coordinating within the SoS and contributing to meet SoS goals.

2.3.2 Characteristics of System of Systems

Based on work done by the INCOSE Systems of Systems Work Group [Dahmann, 2015], the major challenges facing Systems of Systems Engineering (SoSE) have been cataloged in terms of seven points. These challenges are presented in the SoSE section of the INCOSE SE Handbook [Wasson, 2015]. These challenges include:

SoS Authorities. In a SoS each constituent system has its own local "owner", users, business processes and development approach. As a result, the type of organizational structure assumed for most traditional systems engineering under a single authority

responsible for the entire system is absent from most SoS. In a SoS, Systems Engineering (SE) relies on cross-cutting analysis and on composition and integration of constituent systems which, in turn, depend on an agreed common purpose and motivation for these systems to work together towards collective objectives which may or may not coincide with those of the individual constituent systems.

Leadership. Recognizing that the lack of common authorities poses challenges for SoS, a related issue is the challenge of leadership in the multiple organizational environments of a SoS. This question of leadership is experienced where a lack of structured control normally present in SE of systems requires alternatives to provide coherence and direction, such as influence and incentives.

Constituent Systems' Perspectives. Systems of systems are typically comprised, at least in part, of in-service systems, which were often developed for other purposes and are now being leveraged to meet a new or different application with new objectives. This is the basis for a major issue facing SoS SE; that is, how to technically address issues which arise from the fact that the systems identified for the SoS may be limited in the degree to which they can support the SoS. These limitations may affect the initial efforts at incorporating a system into a SoS, and systems' commitments to other users may mean that they may not be compatible with the SoS over time. Further, because the systems were developed and operate in different situations, there is a risk that there could be a mismatch in understanding the services or data provided by one system to the SoS if the particular system's context differs from that of the SoS.

Capabilities and Requirements. Traditionally (and ideally) the SE process begins with a clear, complete set of user requirements and provides a disciplined approach to develop a system to meet these requirements. Typically, a SoS is comprised of multiple independent systems with their own requirements, working towards broader capability objectives. In the best case, the SoS capability needs are met by the constituent systems as they meet their own local requirements. However, in many cases, the SoS needs may not be consistent with the requirements for the constituent systems. In these cases, the SoS SE needs to identify alternative approaches to meeting those needs through changes to the constituent systems or additions of other systems to the SoS. In effect, this is asking the systems to take on new requirements with the SoS acting as the 'user'.

Autonomy, Interdependencies and Emergence. The independence of constituent systems in a SoS is the source of a number of technical issues facing SE of SoS. The fact that a constituent system may continue to change independently of the SoS, along with interdependencies between that constituent system and other constituent systems, add to the complexity of the SoS and further challenges SE at the SoS level. In particular, these dynamics can lead to unanticipated effects at the SoS level leading to unexpected or unpredictable behavior in a SoS even if the behavior of constituent systems is well understood.

Testing, Validation, and Learning. The fact that a SoS is typically composed of constituent systems which are independent of the SoS poses challenges in conducting end-to-end SoS testing as is typically done with systems. Firstly, unless there is a clear understanding of the SoS-level expectations and measures of these expectations, it can be very difficult to assess the level of performance as the basis for determining areas which need attention, or to assure users of the capabilities and limitations of the SoS. Even when there is a clear understanding of SoS objectives and metrics, testing in a traditional sense can be difficult. Depending on the SoS context, there may not be funding or authority for SoS testing. Often the development cycles of the constituent systems are tied to the needs of their owners and original ongoing user base. With multiple constituent systems subject to asynchronous development cycles, finding ways to conduct traditional end-to-end testing across the SoS can be difficult if not impossible. In addition, many SoS are large and diverse making traditional full end-to-end testing with every change in a constituent system prohibitively costly. Often the only way to get a good measure of SoS performance is from data collected from actual operations or through estimates based on modeling, simulation, and analysis. Nonetheless, the SoS SE team needs to enable continuity of operation and performance of the SoS despite these challenges.

SoS Principles. SoS is a relatively new area, with the result that there has been limited attention given to ways to extend systems thinking to the issues particular to SoS. Work is needed to identify and articulate the cross-cutting principles that apply to SoS in general, and to developing working examples of the application of these principles. There is a major learning curve for the average systems engineer moving to a SoS environment, and a problem with SoS knowledge transfer within or across organizations.

2.3.3 Categories of Systems of Systems

In today's interconnected world, SoS occur in a broad range of circumstances. In those situations where the SoS is recognized and treated as a system in its right, a SoS can be described as one of four categories [Maier, 1996] and [Dahmann and Baldwin, 2008]:

Directed - The SoS is created and managed to fulfill specific purposes and the constituent systems are subordinated to the SoS. The component systems maintain an ability to operate independently; however, their normal operational mode is subordinated to the centrally managed purpose;

Acknowledged - The SoS has recognized objectives, a designated manager, and resources for the SoS; however, the constituent systems retain their independent ownership, objectives, funding, and development and sustainment approaches. Changes in the systems are based on cooperative agreements between the SoS and the system;

Collaborative - The component systems interact more or less voluntarily to fulfill agreed upon central purposes. The central players collectively decide how to provide or deny service, thereby providing some means of enforcing and maintaining standards; and

Virtual - The SoS lacks a central management authority and a centrally agreed upon purpose for the SoS. Large-scale behavior emerges—and may be desirable—but this type of SoS must rely on relatively invisible mechanisms to maintain it.

2.3.4 System of Systems Versus Digital Ecosystem

Early in this research, we discussed the relation between DEs and SoS [Saleh and Abel, 2016a]. Based on both the definitions of DE and SoS, we concluded that it is possible to view the System of Systems as a Digital Ecosystem, where different systems of the SoS can be considered as species in the DE. From a functional point of view, we can see that both SE and SoS are composed of different systems operating together to provide value to the user and preserve their working environment. From another perspective, the Systems Engineering's perspective (SE) [SEBoK, 2017], we can see that there are certain aspects that separate SoS from DE. According to [Sage and Cuppan, 2001] and [Karcianas, 2008], the components of DE are designed to work together under the condition of their environment, while the systems composing a SoS are completely

autonomous and designed separately. The decision to construct a SoS is made after the systems are developed and operated. The fact that we will be looking for an added value is what drives the need for SoS. In order to identify the commonalities and differences between the two notions we note:

- Both DE and SoS are compositions of simpler systems.
- Both DE and SoS are embedded in an environment of a larger scale.
- The constituent systems in DE do not have their independent goal, they are not autonomous and their behavior is subject to the rules of the interconnection topology.
- The interconnection rule in DE is expressed as a graph topology.
- The constituent systems in SoS may have their own goals and they are autonomous, semi-autonomous, or organized as autonomous groupings of composite systems.
- There may be a connection rule expressed as a graph topology for the information structures of the constituent systems in a SoS.
- The SoS is linked to an environment where every constituent system enters as an agent with their individual Operational Set, Goals.

The evolution of SoS and its ability to solve problems which cannot be addressed by the traditional view of DE comes from these three major factors:

- **Autonomy:** the systems involved in SoS are at least partially autonomous
- **Local views:** no system has a full global view of the SoS.
- **Decentralization:** information gathering is distributed.

It should be noted that formation of a SoS is not necessarily a permanent phenomenon, but rather a matter of necessity for integrating and networking systems in a coordinated way for specific goals such as robustness, cost, efficiency, etc.

2.3.5 Different Approaches

Different approaches have been proposed in the literature concerning the coordination of the different SoSs. There are mainly three approaches [Lozano et al., 2008]: Leader / Follower, Virtual Structure [Oh et al., 2015] and Behavioral Control [Baizid et al., 2017]. The latter two approaches are directed towards the robotics domain of SoS as they are concerned with controlling the motor functions and skills for a SoS of machines rather ISs.

The leader/follower approach presented in this section serves the following aspects:

- One of our goals in our approach, specified in the first chapter, is to have a centralized access point to organize the resources produced by users within distributed ISs. The leader/follower approach offers a way to achieve this by the dedicated leader system that can be assigned to the task of resources management in the SoS.
- The limitation of communication between different DEs can be solved by the leader/follower approach because the leader can handle the communication interface in this case.
- The follower systems in the leader/follower approach provide the flexibility we seek in a DE to be able to include new systems in its digital environment.

Based on the DE description presented earlier in this chapter we can deploy the work of [Dong and Hussain, 2007] and [McMeekin et al., 2009] to present a model of DE using the model introduced by [Dong and Hussain, 2007] and further elaborated on in [Saleh et al., 2015b]. The idea behind the DE model is simple. It specifies the digital ecosystem to be consisted of three basic parts agents, digital species and an environment [Dong and Hussain, 2007] [Saleh et al., 2015b]. Each species can be viewed as an individual, an organization or a system and has its own role to play. One specialization of species is that they are collaborative and usually work in a group, and a leader leads all other followers in the group. We take this model of the DE and move to present the Leader/Follower model. The environment, according to the definition of DE provided earlier in this study, has the specification of open, loosely-coupled, demand-driven, domain-clustered, self-organized and agent-based.

The model of DE is presented in (Fig. 2.2).

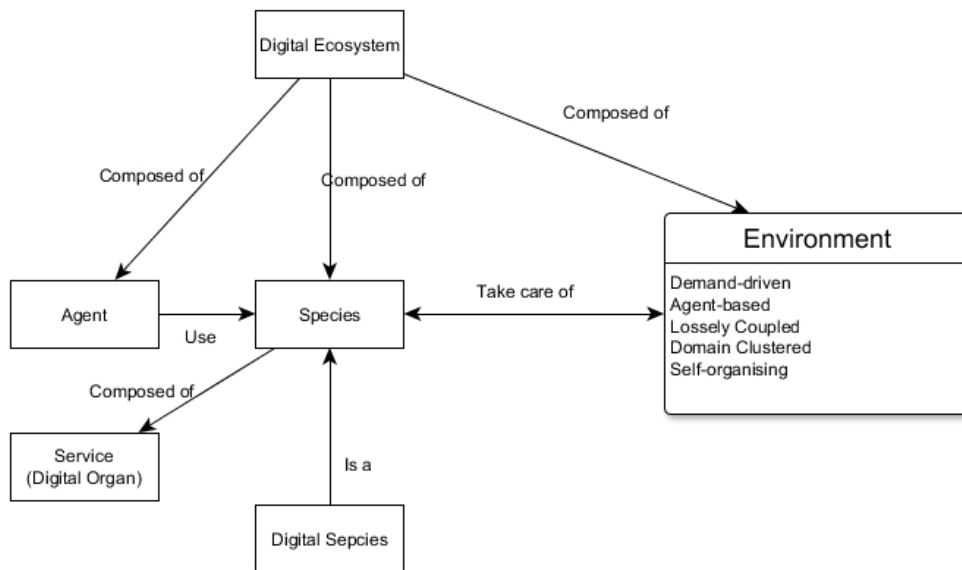


FIGURE 2.2: The model of DE [Dong and Hussain, 2007] [Saleh et al., 2015b].

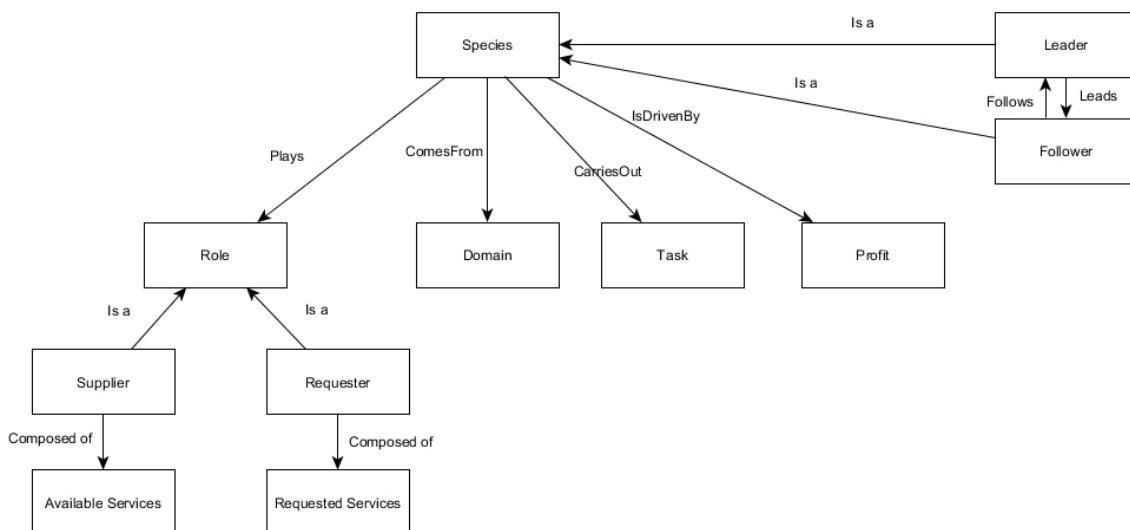


FIGURE 2.3: Leader/Follower model [Dong and Hussain, 2007].

Species is the basic element of DE, which can be defined as the conceptualization of system that is a member in the DE which comes from certain Domain, plays dual Roles including the Supplier who has Available Services and the Requester who has Requested Service, is driven by own Profit and carries out Tasks that relates to the Profit. (Fig. 2.3).

Species refers to the systems that are members of the DE and operate in its environment.

Domain refers to a field in DE where a species has common interest with other species.

Task refers to a mission that a species is executing, to survive and achieve its goals in the environment of Digital Ecosystem.

Profit means a social, economical, or technical advantage that a species gains by working within a DE.

Role refers to the role of a species in the interaction with other species. There are two major roles in DE interactions – Supplier and Requester. Differed from other network architectures in which each agent has fixed role, each species in DE are able to play the dual roles at the same time.

Supplier is a role of a species that provides a service.

Requester is a role of a service that requests a service.

Available Service is a service that a supplier provides.

Requested Service is a service that a requester needs.

In DE, due to the specification of self-organizing and collaboration, species may form a hierarchical organization of flexible structures. In a DE, a leader is selected, to direct the other species' activities and represent the belonged DE to interact with other species. The other species in this DE are directed by the leader and realize their own functions [Chang and West, 2006]. The subclasses of species concept – leader concept and follower concept inherit all properties from species concept. The only difference is the relationship between leader and follower, which a leader leads all followers and all followers follow a leader in a DE. The Leader/Follower model is shown in (Fig. 2.3).

As established earlier, The SoS is a DE with the ability to include new ISs as new member in its environment without the need to design the new ISs to work in coordination with the other systems in the SoS. In fact, the SoS will handle the work load required to reference the resources coming from the new ISs. That means the SoS needs to link to different ISs and allow for collaboration on the resources of these ISs. For that, the SoS needs a leader system to unify resources references and facilitate collaboration on these references.

2.4 System of Information Systems

In this thesis, we are interested in a special type of SoS that is both directed and collaborative. It is directed towards the domain of Information Systems (ISs) and supports collaboration among groups of users. It is called the Systems of Information Systems (SoIS).

The notion of System of Information Systems is defined by [Carlsson and Stankiewicz, 1991] as “networks of agents interacting in a specific technology area under a particular institutional infrastructure for the purpose of creating, diffusing, and utilizing technology focused on knowledge, information, and competence flow.” [Breschi and Malerba, 1996] describe SoIS as “the specific clusters of the firms, technologies, and industries involved in the generation and diffusion of new technologies and in the knowledge flow that takes place among them.”

Based on the definitions provided we can summarize the features of SoIS as follows:

- SoIS addresses the impact of the interrelationships between different ISs.
- SoIS is concerned with the flow of information and knowledge among different ISs.
- SoIS is responsible for generating information from the emergent ISs.
- Information interoperability is a key issue when designing a SoIS.

As explained in the previous section, the SoS is a DE with a roadmap to include new systems as it expands and grows. This is no different for SoIS as it is eventually a special type of SoS.

In this section, we look in the literature and into different commercial products that are directed to facilitate resources management and collaboration in a DE. We list their advantages and disadvantage to justify the need for our SoIS approach to collaboration and resources management.

2.4.1 Accenture's Knowledge Exchange (KX)

At the heart of Accenture's corporate Knowledge Management (KM) efforts was a sophisticated electronic repository system called the Knowledge Exchange (KX). KX housed approximately 7,000 individual databases grouped by industries and topics. KX's primary purpose was to store internally generated knowledge— i.e., client presentations, methodologies, best practices, and past proposals— that could be accessed by its employees using Lotus Notes and the Internet. The KM efforts were managed and promoted by 500 KM staff members around the globe. About 150 knowledge managers focused on the actual database administration at any one time. They synthesized, repackaged, and organized the content to be utilized by consultants [Paik and Choi, 2005].

KX was essential to a consultant's daily work. It was common for a consultant to access more than 10 different databases on a particular day. Most new client projects began with a search of the KX for past experiences on similar projects. Strategy consultants reviewed analyses performed on similar projects to employ a similar methodology or reproduce market research. IT consultants looked for relevant methodologies or procedural templates to follow. Project managers often found best-in-class project plans for managing large engineering teams. Such past analyses, presentations, and project plans helped reduce planning time, minimize risk, and improve the quality of the client deliverable. Our interviewees agreed that KX was the single most important knowledge capturing and transferring tool at Accenture.

As seen in (Fig. 2.4), clients can search and query the many knowledge bases of KX. Nevertheless, Accenture was unable to truly harness and transfer management knowledge across its global organization. According to [Paik and Choi, 2005] there were inconsistent and uneven levels of participation by the consultants. The findings indicate that the problems that Accenture's KM practice faced had little to do with technology, people, or the overall vision. Most had to do with a few very critical elements in the KM plan that Accenture appeared to have overlooked such as insufficient control over resources and weak relations with clients' work schema.



FIGURE 2.4: Accenture's KX main interface

2.4.2 Google Cloud services

Google applications are structured as one or more jobs that run on the Google Cloud backend consisting of many large compute clusters. Jobs consist of one to thousands of tasks, each of which executes on a single machine in a compute cluster [Mishra et al., 2010]. This architecture provides tremendous services to users all around the globe, from simple Google Docs experience to more specialized databases and compute engines.

Google cloud, therefore, produces numerous amount of resources that are compatible and intolerable. What is missing is a way to query the different services of Google cloud and be able to consult resources coming from different systems within the cloud. For example, a developer working in a software development company with other specialist forming a software development team can use different systems from Google Cloud. Google Console can provide the necessary tools to build, test and execute both the backend and frontend of the project, while Google calendar, Google mail, Google docs can be used to organize the workflow and take notes. It would be useful for users to be able to find different resources coming from different systems together using a related indexing schema. (Fig. 2.5) shows the main screen of Google console's API management page that represents all the services available from different systems through an API. This is very encouraging to include these systems in a SoIS and bring together their resources.

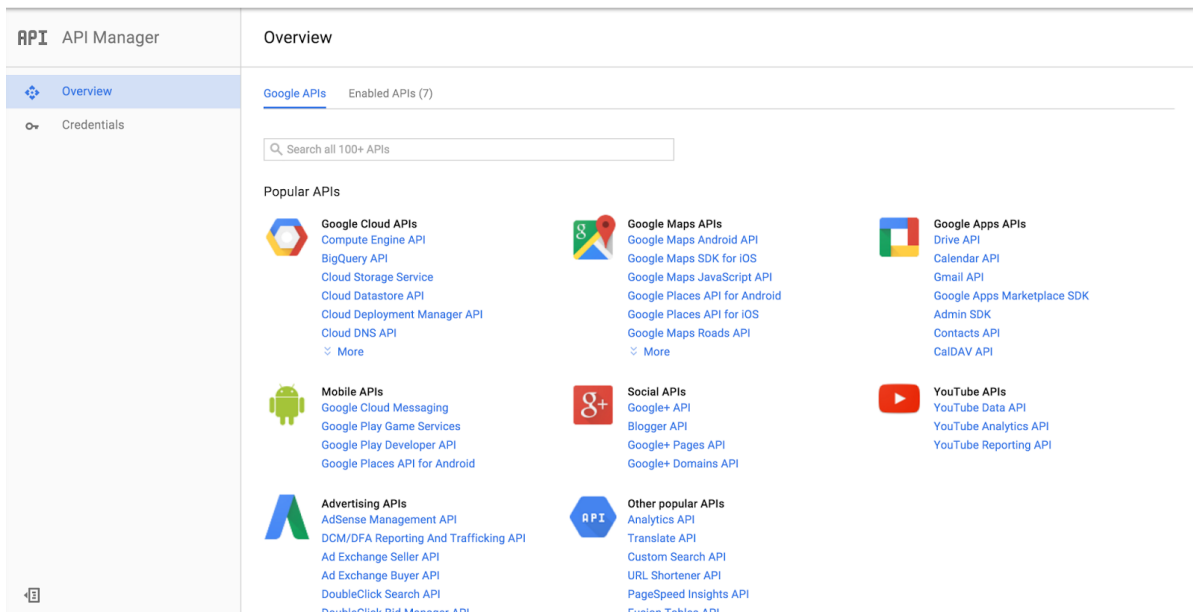


FIGURE 2.5: Google console API management page.

2.4.3 Microsoft Sharepoint

SharePoint Products and Technologies facilitate collaboration within an organization and with partners and customers. Using the combined collaboration features of Microsoft Windows SharePoint Services and Microsoft Office SharePoint Portal Server, users can easily create, manage, and build their own collaborative Web sites and make them available throughout the organization [Rama and Bishop, 2006].

Despite maintaining a huge segment of the content and collaboration market, SharePoint has some major downsides. Organizations that have a well-established on-premises SharePoint deployment seem to have suffered the most according to [Rama and Bishop, 2006] and [Diffin et al., 2010], as their high hopes for the platform's evolving capabilities have been vanished. This is the case especially with documents organization and tagging mechanism in SharePoint. SharePoint has transformed in many ways since the 2010 version but it's clear that Microsoft has a long way to go in addressing usability issues and managing users' expectations when it comes to resources tagging and retrieval. (Fig. 2.6) shows the main interface of Microsoft SharePoint online that supports resources of different types and origin.

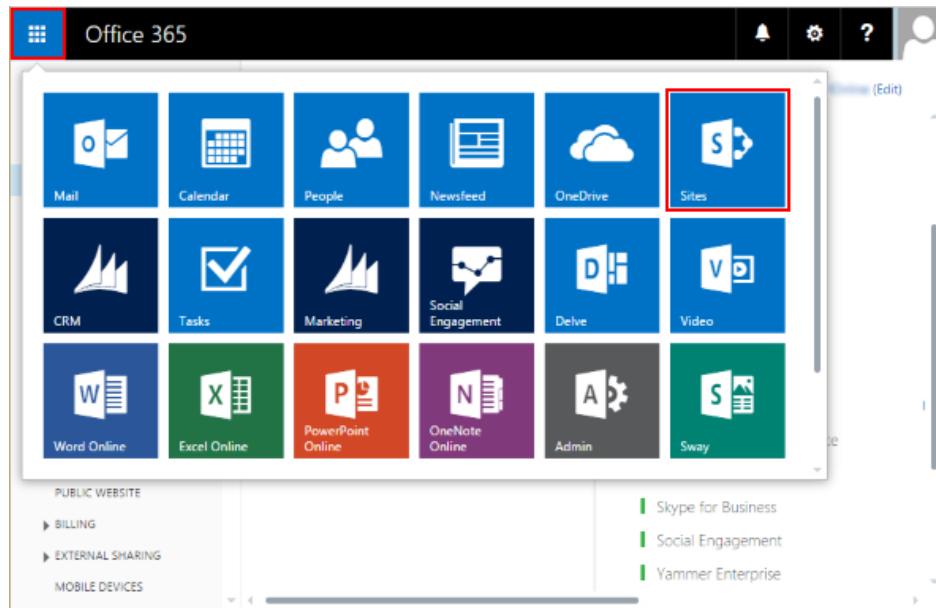


FIGURE 2.6: SharePoint online.

2.4.4 Other Platforms

The work in [Peng et al., 2014] is about collaborative software development platforms for crowdsourcing. According to [Peng et al., 2014], in crowdsourced software development, enterprises delegate many software engineering tasks to external individuals or groups with the support of crowdsourcing platforms. Large IT companies use internal crowdsourcing with software development tasks and their own employees to leverage untapped human resources. The crowdsourcing platform supports the exchange of messages and information among requesters and providers to reduce gaps and ambiguity. It also supports various collaborations by providing the facilities for sharing workspaces and encouraging user interactions. We argue that such platforms, though possess great potentials in terms of communication and collaboration, they lack the ability to open discussion about the work deliverable. Also, it is not possible to reference any resources in those platforms.

In [Bizoi et al., 2009a], authors emphasize the benefits of a Shared Workspace System in a group collaboration platform that allows the creation of documents, appointments, contacts, tasks, and notes within shared workspaces. Using only a web browser, without having to install additional software, the users can access the data anytime, from anywhere in the world. Yet again, the mechanism for organizing the resources produced in such system is missing. To our understanding, sharing spaces are the cornerstones

of any collaborative platform, but the missing ingredient here is the key to index the resources for quick access and retrieval.

Another collaboration platform discussed in [Bizoi et al., 2009a] and [Bizoi et al., 2009b] is phpGroupWare platform. phpGroupWare is a fully featured, web-based messaging, collaboration and enterprise management platform. It is provided with a range of modules (more than 50 applications) that can be selected and installed according to needs. Some of the most powerful features that can be used for multinational team collaboration are: contacts management, email, shared web-based calendar, to-do lists, address book, web content and document management and sharing. One issue we can mark about this product is that most of the organizations already have specialized software for communication, document creation, contact management, etc. What we should focus on in a collaboration platform is the ability to incorporate existent solutions and index their resources.

The aforementioned examples of collaboration platform indicate the need for an encompassing solution to the problem of resources management that takes into consideration the organizations need to communication and sharing while preserving the autonomous nature of the existing Information systems.

2.5 Interoperability between Information Systems

There is a need for a precise definition of interoperability because the term can have various interpretations in different contexts. For example, interoperability between a microcontroller and a sensor operating in a weather system may be addressed via an intermediate interface module. In contrast, communication between large-scale systems may require frequent, automated updates of complex information.

Experts suggest that there are different interpretations of terms such as System of Systems and interoperability, based on divergent needs: “What someone considers to be a system of systems, someone else considers a system.” [Morris et al., 2004] This becomes particularly apparent when discussing hugely complex systems that are really multiple Systems of Systems.

Some of the difficulty associated with defining interoperability is reflected in the many definitions that exist. For example, the IEEE has four definitions of interoperability [Breitfelder and Messina, 2000]:

- the ability of two or more systems or elements to exchange information and to use the information that has been exchanged.
- the capability for units of equipment to work together to do useful functions.
- the capability, promoted but not guaranteed by joint conformance with a given set of standards, that enables heterogeneous equipment, generally built by various vendors, to work together in a network environment.

We may never have agreement on a precise definition due to differing expectations that are constantly changing. New capabilities and functions continue to offer new opportunities for interactions between systems. For the purposes of this thesis, we define interoperability as the ability of a set of communicating entities to (1) exchange specified sets of data and (2) operate on the data according to specified, agreed-upon, operational semantics.

In this part of our thesis, we investigate different interoperability models. These models are described in the following subsections. First we discuss two models ISs interoperability, then the model of the SoS is presented.

2.5.1 Information Systems Interoperability Models

A widely recognized model for system of systems interoperability is Levels of Information System Interoperability (LISI) [Group et al., 1998]. LISI –see (Table. 2.1)– focuses on the increasing levels of sophistication of ISs interoperability.

Five levels are defined:

Level 0 – Isolated interoperability in a manual environment between stand-alone systems: Interoperability at this level consists of the manual extraction and integration of data from multiple systems.

TABLE 2.1: The LISI Interoperability Maturity Model

Information Exchange	Level
Cross-domain information and application sharing Advanced collaboration	4 Enterprise Interactive manipulation Shared data and applications
Shared databases Sophisticated collaboration	3 Domain Shared data "Separate" applications
Heterogeneous product exchange Basic collaboration	2 Functional Minimal common functions Separate data and applications
Homogeneous product exchange	1 Connected Electronic connection Separate data and applications
Manual Gateway	0 Isolated Non-connected

Level 1 – Connected interoperability in a peer-to-peer environment: This relies on electronic links with some form of simple electronic exchange of data. Simple, homogeneous data types, such as voice, text email, and graphics (e.g., Graphic Interface Format files) are shared. There is little capacity to fuse information.

Level 2 – Functional interoperability in a distributed environment: Systems reside on local area networks that allow data to be passed from system to system. This level provides for increasingly complex media exchanges. Logical data models are shared across systems. Data is generally heterogeneous-containing information from many simple formats fused together (e.g., images with annotations).

Level 3 – Domain based interoperability in an integrated environment. Systems are connected via wide area networks. Information is exchanged between independent applications using shared domain-based data models. This level enables common business rules and processes as well as direct database-to-database interactions. It also supports group collaboration on fused information.

Level 4 – Enterprise-based interoperability in a universal environment: Systems are capable of using a global information space across multiple domains. Multiple users

can access complex data simultaneously. Data and applications are fully shared and distributed. Advanced forms of collaboration are possible. Data has a common interpretation regardless of format.

LISI focuses on technical interoperability and the complexity of interoperations between systems. The model does not address the environmental and organizational issues that contribute to the construction and maintenance of interoperable systems (e.g., shared processes for defining interoperability requirements and maintaining interoperability across versions).

Acknowledging the limitation of LISI, Clark and Jones proposed the Organizational Interoperability Maturity Model (OIM), which extends the LISI model into the more abstract layers of command and control support [Clark and Jones, 1999]. Five levels of organizational maturity, describing the ability to interoperate, are defined. These include:

Level 0: independent

Level 1: ad hoc

Level 2: collaborative

Level 3: integrated (also called combined)

Level 4: unified

On one end of the spectrum, at Level 0, no formal framework is in place for interoperation, whereas at Level 4, common goals, value systems, command structure and knowledge bases exist.

2.5.2 The System of Systems Interoperability Model

The models previously discussed address a range of interoperability issues from technical to coalition organizational. The SOS interoperability model has been developed to address technical interoperability and operational interoperability. However, SOS interoperability model goes a step further to address programmatic concerns between organizations building and maintaining interoperable systems.

Interoperation among systems is typically achieved through significant effort and expense. Too often, the approaches used lead to interoperability that is specific to the

targeted systems (sometimes called “point-to-point interoperability”) and that does not facilitate extension to other systems. Even then, the technical approaches employed, such as the Extensible Markup Language (XML) or JavaScript Object Notation (JSON), offer only partial interoperability.

Achieving large-scale and consistent interoperation among systems will require a consistently applied set of management, constructive, and operational practices that support the addition of new and upgraded systems to a growing interoperability web [DiMario, 2006]. Improvements in technology alone (whether XML, JSON or any other) will not be sufficient. There must be parallel improvements in the ways that current and future interoperability needs are identified, and how organizations pursue interoperability.

SoS interoperability model defines three types of interoperability, shown in (Fig. 2.7), within a SoS context – programmatic, constructive, and operational. Programmatic interoperability concerns the linkages between systems to manage information acquisition. Constructive interoperability concerns linkages between organizations that are responsible for system construction that entail architecture, standards, design, commercial off the shelf products, and maintenance. Operational interoperability concerns linkages between systems in their operation or technical interoperability, their interactions with one another, the environment, and with users.

In the discourse of this thesis, we find this model to fit our need for developing a System of Information Systems (SoIS). We start incorporating guidelines from this model early in the process of designing the SoIS, until the implementation phase. To put things in perspective, in order to overcome the interoperability problems in the SoIS, it is not enough to depend on technical solutions. We need an architectural model that allows incorporation of different ISs. We also need a modular semantic model that is capable of defining and describing the various resources and domains of the SoIS.

2.5.3 Limitations of System of Systems Interoperability Model

The three-tiered SOSI model (programmatic, constructive, and operational) provides a useful way to implement our SoIS. However, the model is not sufficient, because it does not provide a solution for issues beyond the scope of programs, such as policies, standards, and work requirements [Wang et al., 2009]. It shows the different levels of

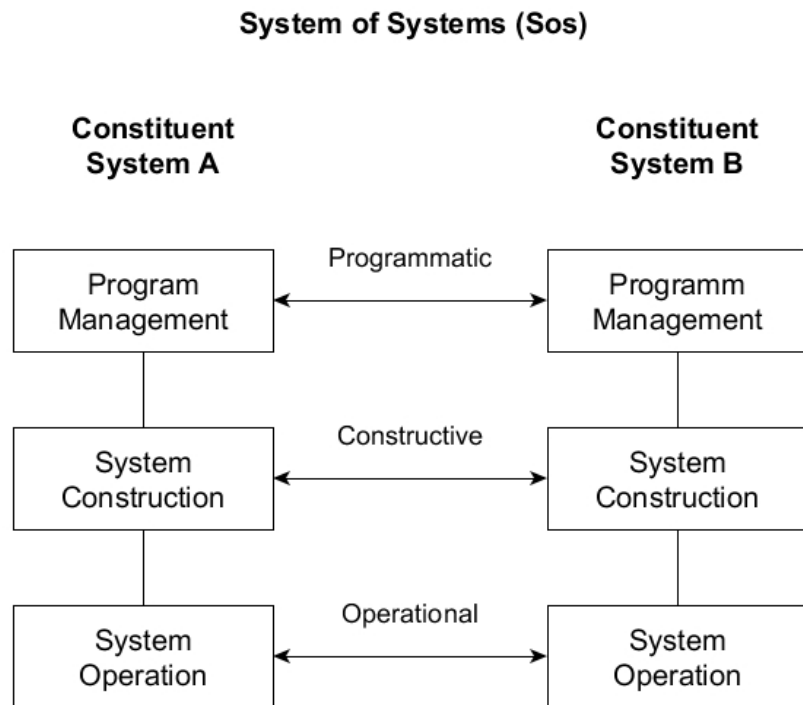


FIGURE 2.7: System of Systems Interoperability Types [Morris et al., 2004]

interoperability that we need to maintain in order to realize the SoIS, but it does not extend to issues like usage policies, resources standardization as we work with heterogeneous resources from different ISs. Adopting the SOSI model in our architectural model allowed us to manage the communication lines between different systems and be able to get resources from them. What comes next is to unify these resources in order to be able to present them and work with them (access, index, share, vote, comment). For that reason, the architectural model for the SoIS takes the leader/follower approach. The leader/follower approach adds to the SOSI model by categorizing the systems in a SOS into two profiles; One system is considered the leader where it represents the centralized access point for resources with all the functionalities available for the end-user. The other systems are considered to be followers where they contribute references of their resources to the leader. In this way the architectural model of the SoIS is based on the SOSI model and the leader/follower approach. That gives it the ability to link different ISs with the leader of SoIS where we can find the unified references of resources coming from different ISs.

2.6 Semantic Web standards and SoIS modeling

The term semantic web was invented by Tim Berners-Lee¹ who supervises the development of the semantic web recommendations. Tim Berners-Lee defines the semantic web as “giving information a well-defined meaning, better enabling computers and people to work in cooperation” [Mikroyannidis, 2007]. The semantic web implements the “Web of data” that links and organizes the information on the Internet. The main goal of the semantic web is to guide the evolution of the web to allow users (without intermediate) to find, share, and combine information more easily. The Semantic Web provides a vision of information that can be readable by humans as by machines. For example, the phrase: “Paris is the capital of France” is understandable by humans, but with the semantic web, it would be understandable also by machines because it offers a solution to characterize resources.

In order to link the data to its information source in the Semantic Web, the data should be qualified [Deparis, 2013]. This qualification of data should be based on a formal reference or model. This formal reference should ensure that there is no ambiguity in the vocabulary used for data qualification. This formal reference is usually represented by ontologies. Taking the context of computer science and information science, [Gruber, 1995] defines the ontology as “an explicit specification of a conceptualization”. The conceptualization for [Gruber, 1995] is “an abstract, simplified view of the world that we wish to represent for some purpose”. Ontologies are considered as “pillars” of the Semantic Web. This is because the ontologies are used to describe the Semantic Web vocabulary. In order to use the ontology for modeling, we have to take a look at its typology.

According to [Heijst et al., 1997], the typology of ontology distinguishes between four levels of ontologies regarding the level of abstraction of the concepts and relations. These levels are:

- High-level ontology (also called top level): A high-level ontology is an ontology that describes the very general concepts which are the same in all areas of knowledge. This ontology decries general concepts such as entity, time, activity, role, etc.

¹inventor of the World Wide Web and director of the World Wide Web Consortium (W3C)

- **Core-ontology:** The core-ontology contains the central concepts of a particular domain. For example, the SIOC (Semantically-Interlinked Online Communities) is a core-ontology that contains concepts describing how to link different discussion methods (e.g. blogs, forums, mailing lists, etc) to each other.
- **Domain ontology:** The domain ontology contains concepts describing a specific domain. This ontology is built from specifications to either high-level ontology or core-ontology. For example, an ontology of a university defines concepts of members that could be found in the university (e.g. students, professors, personnel, etc.), or processes held in the university (e.g. courses, exams, etc.).
- **Application ontology:** The application ontology contains the concepts necessary to model an application of a particular domain. For example, an ontology for modeling a certain course in a university is an application ontology of the domain ontology that models the university in general.

Semantic web standards can be used for the domain and the application model of the SoIS. According to [Lytras and Sicilia, 2005] semantic web standards play important role in organizational modeling. [Huber, 1991] presents knowledge constructs and processes in an organization as follows: knowledge acquisition, knowledge storage, knowledge sharing and knowledge interpretation. Ontologies are the backbone for implementing these four points. This is because ontologies serve as tools for knowledge modeling. Using ontologies, we can describe the knowledge circulating in a particular organization. In addition, we can describe how and by whom the knowledge is shared. Semantic web offers many ontology standard models for knowledge modeling and knowledge sharing. Using Semantic web standards implies respecting a certain level of formality. This level of formality is required when reusing the model or when applying the ontology reasoner. In this thesis, we identify the following semantic web standards to be relevant to describe resources and domains of SoIS:

FOAF (Friend Of A Friend) [Brickley and Miller, 2010]: The FOAF project has started in 2000 to describe persons and their social network in a semantic way. FOAF ontology contains vocabulary and relations describing persons, their activities, the relation among persons and the relation among persons and documents. The following are examples of the classes and relations that could be found in FOAF:

- **Person:**

- class: *foaf:Person*.
- relations: *foaf:firstName*, *foaf:lastName*, *foaf:gender*, *foaf:phone*, etc.

- Agent:
 - class: *foaf:Agent*, *foaf:Group*, *foaf:Person*, *foaf:Organization*.
 - relations: *foaf:member*, *foaf:maker*, etc.

- User account:
 - class: *foaf:OnlineAccount* with its sub-classes (*foaf:OnlineChatAccount*, *foaf:OnlineEcommerceAccount*, etc.).
 - relations: *foaf:accountName*, etc.

- Social network:
 - class: *foaf:Group*
 - relations: *foaf:knows*

- Document
 - class: *foaf:Document*, *foaf:Image*.
 - relations: *foaf:title*, *foaf:topic*, *foaf:publications*.

In order to represent the meta-data of the documents, FOAF ontology uses Dublin Core² (DC). The original Dublin Core meta-data element set consists of 15 meta-data elements. Examples of these elements are: Title, Creator, Subject, Description, Publisher, etc.

Here is a concrete example of using FOAF to define a person using FOAF (the person is an agent) (kb is the namespace of the knowledge base):

- *foaf:Person a foaf:Agent.*

- *kb:John a foaf:Person.*

²For more details: <http://dublincore.org/>

- *kb:John foaf:lastName "Doe"*.
- *kb:John foaf:firstName "John"*.
- *kb:John foaf:gender "male"*.

SIOC (Semantically-Interlinked Online Communities) [Breslin et al., 2009]: SIOC is a vocabulary for describing objects of online community sites and their relationships. It provides the necessary elements to model different types of discussions such as weblogs, message boards, wikis, forums, mailing lists, etc. To give an example, SIOC models a social group of users who communicate with each other by using the *sioc:Usergroup* class. This class is useful when describing groups of users within a social Web application. Every group in SIOC has a space denoting a place where the data of the group resides. The SIOC space is represented by the class *sioc:Space*.

SIOC uses other ontologies to enrich the description of described information. For example, SIOC uses FOAF ontology to provide the creator of a message using the relation *foaf:maker*. SIOC also extends some classes in FOAF, for example the class *sioc:UserAccount* is a specialization of *foaf:OnlineAccount*. This specialization permits to link the user account of a SIOC to a person described by FOAF using the relation *foaf:account*.

Here is a concrete example of using SIOC to define a user account, his group and its space (kb is the namespace of the knowledge base):

- *kb:John_account a sioc:UserAccount*.
- *kb:John foaf:account kb:John_account*.
- *kb:groupA a sioc:Usergroup*.
- *kb:groupA sioc:has_member kb:John_account*.
- *kb:John_account sioc:member_of kb:groupA*.

BIBO (BIBliographic Ontology) [D’Arcus and Giasson, 2009]: The main objective of BIBO project is to describe bibliographic references for the Semantic Web. Using BIBO, we can describe books, conferences, papers, documents, etc. The main class of BIBO is *bibo:Document* which is equivalent to FOAF class *foaf:Document*. BIBO also

uses FOAF for describing the author of a document by using the relation *foaf:maker*. The meta-data of the document is described in BIBO using the Dublin Core (DC) vocabulary.

Here is a concrete example of using BIBO to describe a scientific paper published in a journal (kb is the namespace of the knowledge base):

- *<kb:doi/10.5220/0005082602370244>a bibo:Article;*
- *dc:title "Investigating the similarity between collaboration systems and digital ecosystems.";*
- *bibo:pageStart "30";*
- *bibo:pageEnd "35";*
- *dc:creator foaf:majd;*
- *dc:creator foaf:marie_helen;*
- *dc:creator foaf:Veronique;*
- *bibo:authorList (<http://xmlns.com/foaf/0.1/majd>
<http://xmlns.com/foaf/0.1/marie_helen>
<http://xmlns.com/foaf/0.1/veronique>).*

OA (Open Annotation) [Robert et al., 2013]: The work on Open Annotation ontology is conducted by the W3C Open Annotation Community Group³. This group is founded by the Annotation Ontology initiative and the Open Annotation Collaboration. The main objective of this group is to define a semantic model for annotating digital resources. In 2013, the first specifications of this model is published under the Open Annotation data model (OA).

The OA identifies the relation between an annotation and a resource. OA defines the annotation as being a relation between the annotating data and the annotated data. This relation consists of a “body” (the annotating data or the content of the annotation) and a “target” (the annotated data or the resource being annotated). The “body” of the annotation describes its “target”. In OA, the type “body” and the

³<https://www.w3.org/community/openannotation/>

“target” could be a text, a sound, a video, a web page or any resource on the web. The “body” and the “target” could have the same type (e.g. an image annotating another image). The OA uses the Dublin Core (DC) to indicate the format, language, etc. of the “body” and the “target”. The OA uses the FOAF ontology to represent who added the annotation.

Here is a concrete example (taken from the official website of OA) of using OA to represent an annotation. The “target” of the annotation is a webpage containing a big picture taken on Venice Beach in California and depicting the musician Harry Perry. The “body” of the annotation is a Wikipedia page about Harry Perry. (kb is the namespace of the knowledge base):

- *kb:anno a oa:Annotation;*
- *oa:hasTarget <http://www.foaffy.org/gallery2/main.php?q2_itemId=11496>;*
- *oa:hasBody <http://en.wikipedia.org/wiki/Harry_Perry_%28musician%29>;*
- *oa:annotatedBy kb:john;*
- *oa:annotatedAt "2015-02-12T15:02:14Z".*
- *<http://www.foaffy.org/gallery2/main.php?q2_itemId=11496>*
dc:format "text/html".
- *<http://en.wikipedia.org/wiki/Harry_Perry_%28musician%29>*
dc:format "text/html".

VCard [Renato and M., 2014]: VCard is a special format for describing business cards of people and organizations. VCard contains name, address, phone numbers, e-mail addresses, URLs, logos, photographs, etc. The VCard ontology’s main objective is to provide an equivalent representation of VCard utilizing the Semantic Web. The VCard ontology is created in 2001. Since then, new vocabularies has appeared (FOAF [Brickley and Miller, 2010], The Organization Ontology [Reynolds, 2014]). The FOAF ontology describes people and relations between them. The organization ontology focuses on the organization structure. So there are overlaps between the three ontologies FOAF, the organization ontology and VCard. In spite of these overlaps, these ontologies provide useful information and enhanced modeling when used collaboratively.

The VCard class is the main class in the VCard model. This class is equivalent to the new Kind class, which is the parent for the four explicit types of VCards (Individual, Organization, Location, Group). Other classes in VCard include Individual, Name, Address, Telephone.

Here is a concrete example of using VCard to describe a VCard for an individual (kb is the namespace of the knowledge base):

- *kb:ind a vcard:Individual.*
- *kb:ind_name a vcard:Name.*
- *kb:ind_name vcard:givenName "John".*
- *kb:ind_name vcard:familyName "Doe".*
- *kb:ind_telephone a vcard:Telephone.*
- *kb:ind_telephone vcard:telephone "33 6 06 91 00 92".*
- *kb:ind_telephone rdf:type vcard:Work*
- *kb:ind_address a VCard:Address*
- *kb:ind_address vcard:streetAddress "138 rue d'Alsace Lorraine".*
- *kb:ind_address vcard:locality "Compiègne".*
- *kb:ind_address vcard:region "Picardie".*
- *kb:ind_address vcard:postalCode "60200".*
- *kb:ind_address vcard:country "France".*

2.7 Recommender System

Recommender systems are a subclass of information filtering system that seek to predict the “rating” or “preference” that a user would give to an item [Ricci et al., 2011]. It is nowadays an active research topic in the data mining and machine learning fields. With no doubt, in the field of business, recommender systems have also become extremely common in recent years. Recommender systems are changing from novelties

used by a few e-commerce sites, to serious business tools that are re-shaping the world of e-commerce. Many of the largest commerce Web sites are already using recommender systems to help their customers find products to purchase. A recommender system learns from a customer and recommends products that he/she will find most valuable among the available products.

Recommender systems are not merely limited to the usage of providing a shopping list. They are based on user behaviors, watching people in their natural environment and making design decisions directly on the results. In the field of social networks, it also facilitates and ameliorates users experience. Social Recommender Systems (SRSs) aim at alleviating information overload over social media users by presenting the most attractive and relevant content. SRSs also aim at increasing adoption, engagement, and participation of new and existing users of social media sites. Recommendations of content (blogs, wikis, etc.) [Guy et al., 2010], tags [Sigurbjörnsson and Van Zwol, 2008], people [Guy et al., 2009], and communities [Chen et al., 2009] often use personalization techniques adapted to the needs and interests of the individual user, or a set of users [Jannach et al., 2010]. No matter in what domain recommender systems are applied, they are always based on three things: users activities, features of “entities” to recommend to, and features of “items” to be recommended. Here “entities” and “items” are not limited to the pair of “customers” & “books” or “audience” & “films.”

Information retrieval in the context of SoS remains a challenge. In the literature, this challenge is generally addressed by considering the profile of users. In particular, it is addressed in the work on information filtering in order to propose to users relevant resources. In the context of information filtering, several approaches are possible:

- content-based approach [Pazzani and Billsus, 2007] which makes recommendations by comparing the semantic content of resources with the user’s tastes;
- knowledge-based approach [Burke et al., 1996] which makes recommendations using user knowledge and pre-established heuristics;
- collaborative filtering approach [Goldberg et al., 1992] that makes recommendations by analyzing both the user’s opinions about the resources he has visited and those of other users on the same resources.
- Hybrid Recommender Systems that are based on the combination of collaborative filtering and content-based filtering.

In this section, for each type, we review previous work, advantages and technical problems they may encounter.

2.7.1 Collaborative Filtering

Collaborative filtering (CF) is the process of filtering information or patterns using techniques which involves collaboration among various agents, viewpoints, data sources, etc. [Terveen and Hill, 2001]. Applications of CF involve very large data sets. CF methods have been applied to many different kinds of data including: financial data, such as financial service institutions that integrate many financial sources; monitoring and sensing data, such as in mineral exploration, environmental sensing over large areas or multiple sensors; or in e-commerce and web applications where the focus is on user data, etc.

The goal of this approach is trying to predict the opinion a user will hold on different items and to recommend the “best” item to each user based on previous opinions and those of similar users [Negre, 2015]. The typical workflow of a CF system is as the following:

- A quantity of users’ preference is registered;
- A subgroup of users are recognized whose preference is similar to that of the user that is looking for recommendation;
- An average preference of this subgroup is calculated;
- A preference function is used for recommending opinions/items to the user looking for recommendations.

The CF recommender system has the following advantages [Negre, 2015]:

- It uses the score of other users to evaluate a current user’s interest;
- It tries to find users or group of users that have corresponding interests with current user;
- The more there are users and scores, the better the recommending result is.

However, it also has the following disadvantages:

- Finding users or group of users having mutual interests is difficult;
- The recommender system works badly when the scores of users on items are sparse (large amount of users and items, each user merely scores a few items);
- There exists a “cold-start” problem meaning that when a user starts to use the recommender system, his/her interest is unknown. Likewise, if a new item is included into the system, no users have ever given it a score.

For a collaborative filtering, users, where data is collected from, do not really collaborate with each other. It is the data that describes user preferences and behaviors that actually “collaborate,” namely be compared and exploited by different algorithms.

2.7.2 Content-based Filtering

Content-based filtering methods are based on the description of items and a profile of the user’s preference [Brusilovsky and Maybury, 2002]. These algorithms try to recommend items that are similar to those that a user liked in the past or is examining in the present. In particular, various candidate items are compared with items previously rated by the user and the best-matching items are recommended. The system creates a content-based profile of users based on a weighted vector of item features. The weights denote the importance of each feature to the user and can be computed from individually rated content vectors using a variety of techniques. Simple approaches use the average values of the rated item vector while other sophisticated methods use machine learning techniques such as Bayesian Classifiers, cluster analysis, decision trees, and artificial neural networks in order to estimate the probability that the user is going to favor the item [Noguera et al., 2017].

Compared to collaborative filtering, content-based method focus on the distance between items to be chosen and items that already have been preferred by the current user. Instead, collaborative filtering methods need ratings from other users in order to find the ‘nearest neighbors’ of the current user, i.e. users that have similar tastes since they rated the same items similarly. Then, only the items that are most liked by the neighbors of the active user will be recommended. Thus a content-based method depends less on relation among users.

The standard of recommended items proposed by content-based methods has clearer explanations on how the recommender system works since they can be provided by explicitly listing content features or descriptions. Those features are indicators to consult in order to decide whether to trust a recommendation. Conversely, collaborative systems are different since the only explanation for an item recommendation is that unknown users with similar tastes were in favor of that item.

As for shortcomings, a key issue with content-based filtering is whether the system is able to learn user preferences from user's actions regarding one content source and use them across other content types. Content-based recommenders have no inherent method for finding something unexpected. The system suggests items whose scores are high when matched against the user profile; hence the user is going to be recommended items similar to those already rated. This drawback is also called serendipity problem to highlight the tendency of the content-based systems to produce recommendations with a limited degree of novelty. Thus it is probable that an online store will recommend you another model of dust cleaner only because you have recently bought one.

2.7.3 Knowledge-based Recommender Systems

The knowledge-based recommender systems are a specific type of recommender systems that are based on explicit knowledge about the item assortment, user preferences, and recommendation criteria (i.e., which item should be recommended in which context?) [Burke, 1999]. These systems are applied in scenarios where alternative approaches such as collaborative filtering and content-based filtering cannot be applied. A major strength of knowledge-based recommender systems is the non-existence of cold-start (ramp-up) problems since its recommendations do not depend on a base of user ratings. A corresponding drawback is potential knowledge acquisition bottlenecks triggered by the need of defining recommendation knowledge in an explicit fashion.

There exist two types of approaches on knowledge-based recommender system: case-based approach ([Trewin, 2000]; [Mirzadeh et al., 2005]; [Ricci and Nguyen, 2007]; [Smyth et al., 2004]) and constraint-based approach ([Felfernig et al., 2007]; [Thompson et al., 2004]). Case-based approach treats recommendation as a problem of evaluating similarity. Looking for an item that is the most similar to what the current user

considers to be desirable needs knowledge and preoccupation of a domain. Constraint-based recommendation requires the explicit definition of questions, product properties, and constraints. These elements constitute a recommender knowledge base which can be represented as a constraint network [Felfernig and Burke, 2008].

2.7.4 Hybrid Recommender Systems

One difficult, though common, problem for a recommender system is the cold-start problem, where recommendations are required for items that no one in the data set has yet rated [Schein et al., 2002]. In the content-based approach, the system must be capable of matching the characteristics of an item against relevant features in the user's profile. In order to do this, it must first construct a sufficiently-detailed model of the user's tastes and preferences through preference elicitation. The cold start problem would imply that the user has to dedicate an amount of effort using the system – contributing to the construction of their user profile – before the system can start providing any intelligent recommendations.

In the collaborative filtering approach, the recommender system would identify users who have mutual preferences (e.g. rating patterns) with the current user, and propose items which the like-minded users favored (and the current user has not yet seen). Due to the cold start problem, this approach would fail to consider items which no-one in the community has rated previously.

Hybrid recommender systems are based on the combination of collaborative filtering and content-based filtering. These overcome the limitations of native CF approaches. It improves the prediction performance. Importantly, it overcomes the CF problems such as cold-start problem and sparsity. Given two or more basic recommender system techniques, several ways have been proposed for combining them to create a new hybrid system [Burke, 2007]. However, they have increased complexity and are expensive to implement [Ghazanfar et al., 2012]. Usually, most of the commercial recommender systems are hybrid, for example, Google news recommender system [Das et al., 2007].

2.7.5 Limitations of Recommender Systems

A typical recommender system recommends items to users or customers. These items are homogeneous and come from one system. The previously portrayed recommender systems fails to meet our need for recommending resources from different ISs. In the SoS we deal with heterogeneous resources coming from different ISs. Nevertheless, these resources may present a degree of relevance for the same subject. This degree of relevance is established on the basis of users' actions in the leader system of the SoS, users' profiles, and the value of votes. Taking these three factors into consideration (users' actions, users' profiles, and users' votes) allowed us to create the algorithm for recommending heterogeneous resources to users in the SoS.

2.8 Summary

In this chapter, we provided thorough literature review about the key factors concerned in this thesis. The chapter started with the notion of the ecosystem. We defined the terms of Business Ecosystem, Digital Ecosystems (DE), and Learning Ecosystem. We established the attributes that define a Digital Ecosystem. We concluded that a DE is a construct that is built to maintain the complexity of our increased use of technology. However, the DE has limitations. It does not have the ability to expand to include new systems unless these systems are designed to work in the environment of the DE. On the other hand, the System of Systems (SoS) is by itself a DE that allows for adding new systems without having to change the behavior of the new system or the SoS. A special type of SoS, the System of Information Systems (SoIS) is the main concern of this thesis. We seek to distinguish between the SoS and the SoIS by specifying the latter only includes ISs as constituent members. For the purpose of diffusing the problem of interoperability in a SoIS, we reviewed the state-of-the-art of different interoperability models. We decided to follow the dictation of the system of systems interoperability model. The choice of this interoperability model has led to the need to use a semantic model to describe the domain and the application of the SoIS. Hence, we reviewed the semantic web standards and how they can be used to provide a modular model of the SoIS. Finally, we explored the different models of recommender systems as they can be used in the environment of the SoIS to provide added value to users.

Chapter 3

Our Approach

3.1 Introduction

The System of Information Systems is a Digital Ecosystem with the difference of being able to include new ISs that are not designed to work in its digital environment. In order to move from a DE to SoIS we propose a semantic model. This model captures the collaborative nature of the SoIS, along with representing the different ISs, resources, and features of the SoIS. Also, the proposed model allows to design the SoIS in a way that will preserve the autonomous nature of its constituent ISs and allow for adding new ISs with least required effort. The goal of the SoIS is not only to link different ISs together, but also to provide an added value that was not possible to maintain when those systems were operating separately. Several points need to be taken into consideration for the model of SoIS. One, it should adopt the Leader/Follower approach for DE to facilitate working with new ISs and provide a centralized access point with all the necessary functionalities and added value for the user. Two, the model should be modular and adapt to change. lastly, three, the model should be based on semantic web standards for formality.

The chapter is organized as follows: Section 3.2 justifies the choice of MEMORAE-core2 model as the model for our leader system. Then, the semantic model of the SoIS is presented in section 3.3. After that, our algorithm of the heterogeneous resources recommender system is presented in section 3.4. Then, the architectural model of the SoIS is presented in section 3.5. Finally, we conclude with the chapter summary in section 3.6.

3.2 Choice of MEMORAe Approach

MEMORAe approach aims to manage heterogeneous information resources within organizations and to facilitate collaboration and organizational learning. Collaboration is considered from the point of view of sharing and exchanging heterogeneous knowledge resources between collaborators around the shared repository. The MEMORAe-core2 model employs the semantic web standards (SIOC, FOAF and BIBO).

The MEMORAe approach recommends distinguishing two ontological levels for modeling, one generic (domain ontology), the other specific to a particular organization (application ontology).

Regarding the application ontology, it is dedicated to the purpose of the collaboration. It concerns the business knowledge of the organization: what employees share or exchange among each others. The ontological concepts of the domain ontology (1) define the organizational knowledge based on a shared terminology; (2) index resources using nodes presented to the user in the form of a knowledge map (the map of shared terminology). This cartographic presentation make it possible to have a knowledge map of shared terminology and to navigate the nodes of the map to access the resources they index. The map will be different depending on the purpose of the organization.

Regarding the domain ontology, it is dedicated to collaborative processes. It must therefore define the knowledge specific to the implementation of organizational learning through the sharing and exchanging of resources. In order to facilitate collaboration over such resources, the approach recommends defining this level by means of a modular collaboration model exploiting web standards according to the type of resources to be processed.

The rest of this section is dedicated to present the MEMORAe-core2 model and its modules. We also justify the use of this model for the leader system of the SoIS.

3.2.1 MEMORAe-core2 Model

The MEMORAe-core2 collaboration model was developed as part of the MEMORAe approach [Abel, 2015]. The model of MEMORAe-core2 considers an organization as a group of members interacting with each others. Those members are modeled as users with the MEMORAe-core2 model. Every user is associated with one or more

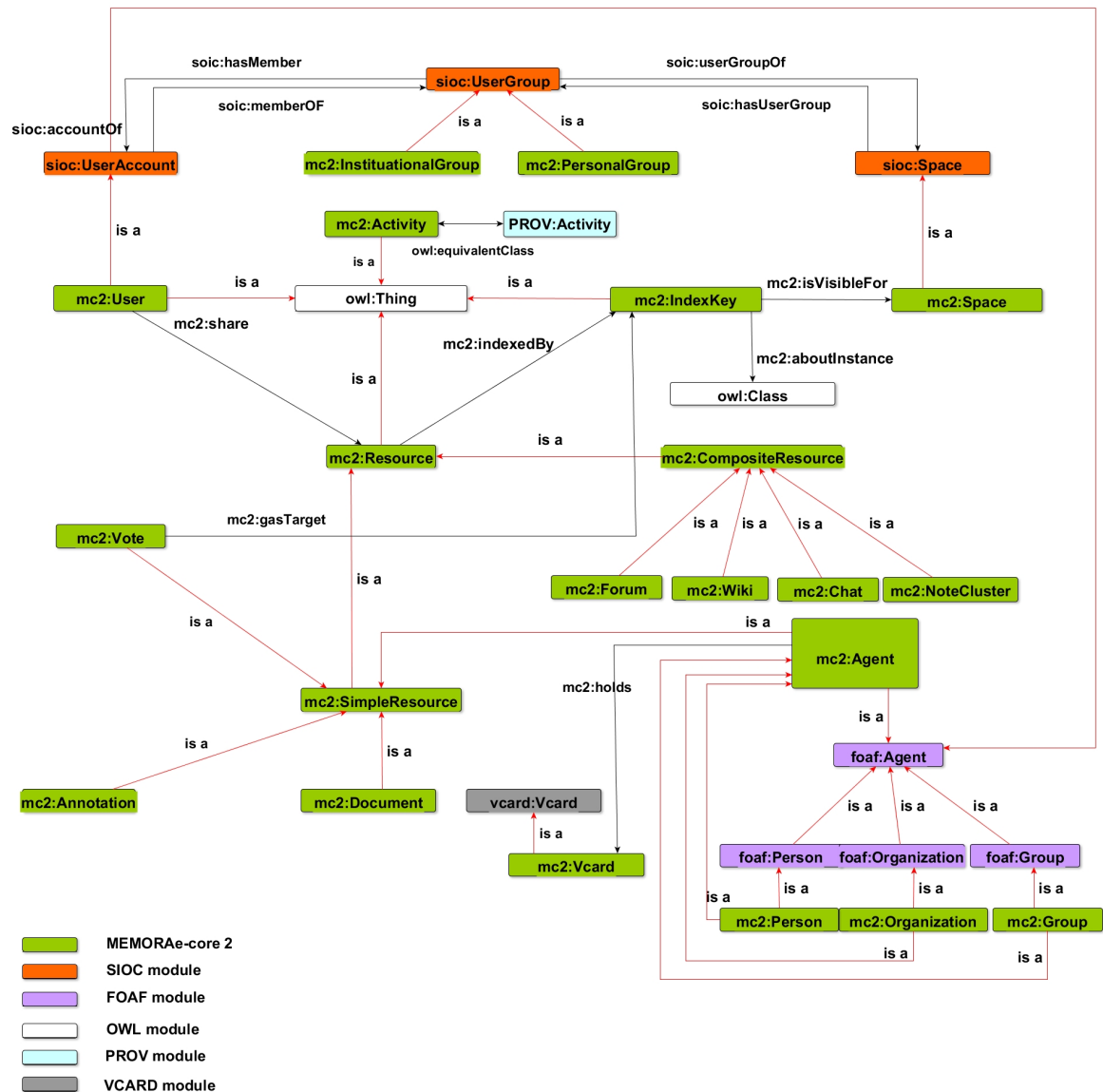


FIGURE 3.1: General view of the MEMORAe-core2 model with its main modules.

sharing spaces that will allow the sharing of heterogeneous resources. The model also provides the user with access to several knowledge bases in the form of a semantic map of concepts. The concepts of the map represent an indexing schema for users to index their resources. In addition, MEMORAe-core2 model gives the users the ability to vote and comment on resources to highlight certain values. Developed from the MEMORAe-core2 model, the leader system in the SoIS has potentials of offering users the following features:

- Accessing resources coming from different information systems in one Centralized location.

- Creating resources using a dedicated information system. These resources can be accessible either from the SoIS or from the dedicated system where they are created.
- Organizing resources around a shared repository presented in the form of a map.
- Sharing resources in different sharing spaces.
- Annotating resources to highlight some related ideas.
- Voting and commenting on resources.
- Tracing users' activities in the SoIS (Who did what and when?)
- Deploying users' traces, users' profiles, and voting scores to recommend useful resources to the right user under a specific topic.

We choose the MEMORAe-core2 model to proceed to the following:

- Implement the leader system of the SoIS in a way that will allow searching for resources in different ISs. The leader system also adheres to the MEMORAe-core2 model which will give the benefits listed earlier (sharing, indexing, voting, and commenting on resources).
- Realize the model of the SoIS as MEMORAe-core2 modular nature allow us to extend it and represent the aspects of the SoIS.

(Fig. 3.1) shows a general view of the MEMORAe-core2 model with its main module. FOAF and SIOC modules are the main parts for modeling organizations. All concepts in MEMORAe-core 2 ontology starts with the prefix "mc2" indicating its namespace. The rest of this section is dedicated to focus on certain aspects of the MEMORAeSoIS model to get the big picture of the modules composing the MEMORAe-core2 model. The complete OWL notation for the model is presented in appendix A.

To better understand the model we go back to the use case scenario mentioned in chapter 1 section 5 and represent it with rdfs triples.

John Doe is a college student and he joins a study group composed of his peers. Ordinarily, they discuss and share information concerning the courses they take.

- mc2:Agent rdfs:subClassOf foaf:Agent
- mc2:Person rdfs:subClassOf foaf:Person
- mc2:Person rdfs:subClassOf mc2:Agent
- mc2:Organization rdfs:subClassOf foaf:Organization
- mc2:Organization rdfs:subClassOf mc2:Agent
- mc2:Group rdfs:subClassOf foaf:Group
- mc2:Group rdfs:subClassOf mc2:Agent

The previous set of triples show how we integrate FOAF model and utilize its standard concepts for the MEMORAE-core2 model.

We can add the knowledge base (kb as a prefix) in the following triples. Looking back to the scenario we mentioned in this section, we create John as a person agent:

- kb:John a mc2:Person
- kb:John a foaf:Person (BY INFERENCE)
- kb:John foaf:firstName “John”
- kb:John foaf:lastName “Doe”

To create a group agent for the studying group:

- kb:StudyGroup a mc2:Group
- kb:StudyGroup a foaf:Group (BY INFERENCE)

To create an organization agent:

- kb:Utc a mc2:Organization
- kb:Utc a foaf:Organization (BY INFERENCE)
- mc2:UserAccount owl:equivalentClass sioc:UserAccount
- mc2:Space owl:equivalentClass sioc:Space
- mc2:InstitutionalGroup rdfs:subClassOf sioc:Usergroup
- mc2:FreeGroup rdfs:subClassOf sioc:Usergroup
- mc2:PersonalGroup rdfs:subClassOf sioc:Usergroup

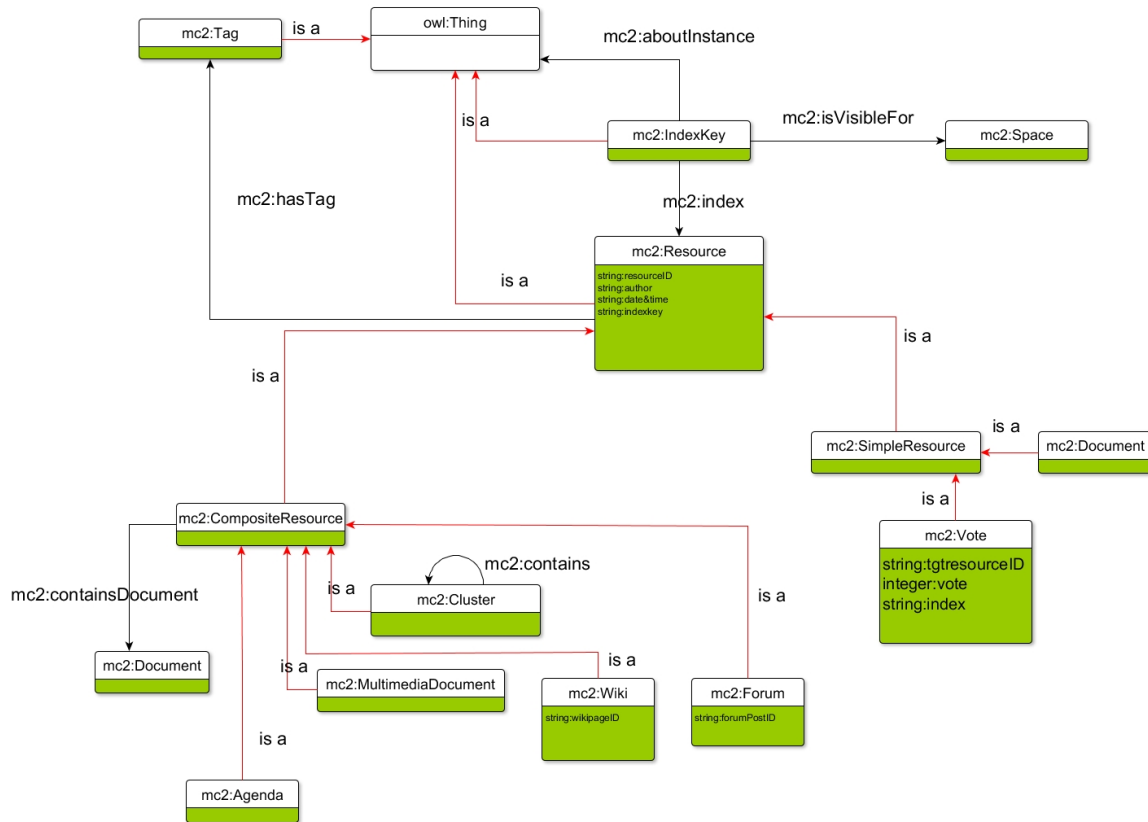


FIGURE 3.2: Resource module as a part of the whole MEMORAe-core2 model.

3.2.2 Resources Module

Resources in MEMORAe-core2 model are divided into two concepts; simple resources and composite resources. This division allows us to categorize resources based on their complexity levels and help in integrating wide range of resources from simple documents to complex wiki pages and forums under the control of the user [Atrash et al., 2015]. As shown in (Fig. 3.2), each resource is indexed by an index key. This index key comes from a map of shared terminology among collaborators in a certain organization. Each concept of the map is associated with a unique index key. This way different types of resources can be found under a single index key, i.e. a concept of the map. This helps the user to find the semantically related resources of different types in one place. Also, each resources can be associated with a tag for search purposes. Resources can be shared with different groups of users belonging to different sharing spaces. This is made possible with the concept of space that is derived from SIOC ontology.

According to this representation of resources in MEMORAe-core2 model, we can easily expand the model to contain resources coming from external systems. For example, instead of developing our own wiki functionality we can rely on an existing wiki system and apply the same indexing schema to the resources coming from that system. This is essential when we want to move from a DE to SoIS and introduce the SoIS to new organizations. By following this representation of resources, we can implement the SoIS in an organization and keep all different kinds of systems in use. It makes no difference for the index key how and where the resource is created.

3.2.3 User Account Module

The user account module, as seen in (Fig. 3.3), is instantiated from SIOC ontology. Each person involved in the work process has one account or more. The account is associated with a role.

To integrate, we can add the knowledge base (kb as a prefix) in the following triples. We create an instance of person kb:john for John and assign a user account to this person:

- kb:JohnAccount a mc2:UserAccount
- kb:JohnAccount a sioc:UserAccount (BY INFERENCE)
- kb:John mc2:hasUserAccount kb:JohnAccount

To create a personal group and sharing space for John:

- kb:JohnGroup a mc2:PersonalGroup
- kb:JohnGroup a sioc:Usergroup (BY INFERENCE)
- kb:JohnSpaceOfGroup a mc2:Space
- kb:JohnSpaceOfGroup a sioc:Space (BY INFERENCE)

To assign the user account of John to his personal group:

- kb:JohnAccount sioc:memberOf kb:JohnGroup
- kb:JohnGroup sioc:hasMember kb:JohnAccount

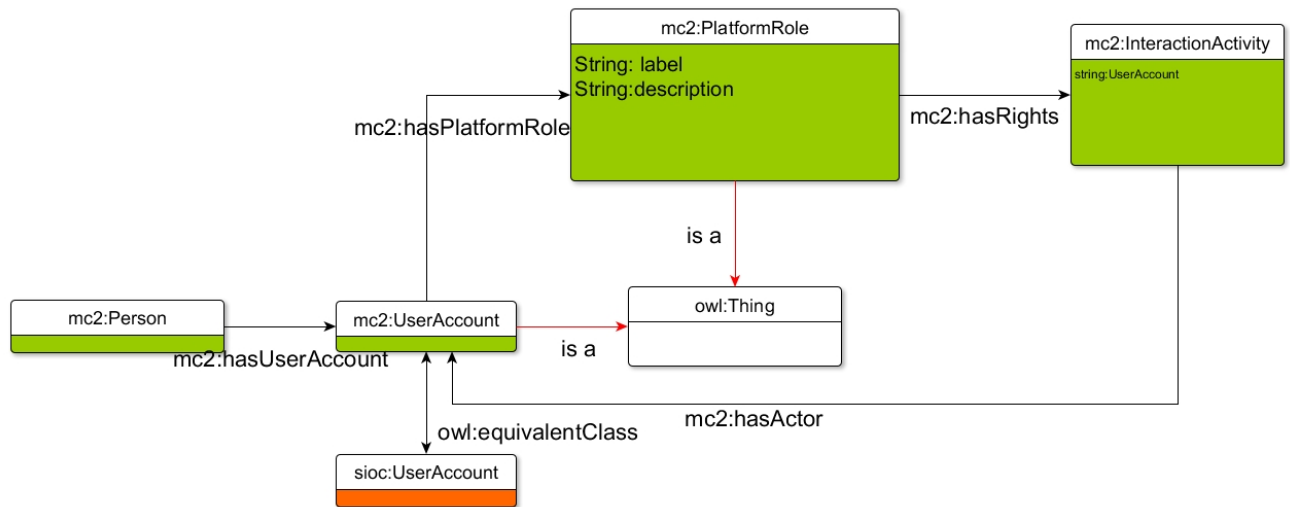


FIGURE 3.3: User account module as a part of the whole MEMORAE-core2 model.

To assign the sharing space to the group:

- kb:JohnGroup sioc:UsergroupOf kb:JohnSpaceOfGroup
- kb:JohnSpaceOfGroup sioc:hasUsergroup kb:JohnGroup

Every person has a personal group which holds a personal sharing space. John can use this group to add and review personal information resources. John also belongs to another group which is an Institutional Group (which has all the members of the study group).

To create the institutional group and its sharing space:

- kb:StudyGroup a mc2:InstitutionalGroup
- kb:StudyGroup a sioc:Usergroup (BY INFERENCE)
- kb:StudySpaceOfGroup a mc2:Space
- kb:StudySpaceOfGroup a sioc:Space (BY INFERENCE)

To assign the sharing space to the group:

- kb:StudyGroup sioc:UsergroupOf kb:StudySpaceOfGroup
- kb:StudySpaceOfGroup sioc:hasUsergroup kb:StudyGroup

To assign the user account of John to the study group:

- kb:JohnAccount sioc:memberOf kb:StudyGroup
- kb:StudyGroup sioc:hasMember kb:JohnAccount

So John belongs to two groups, one personal and the other shared with his study group colleagues. According to his needs, he could choose between the two spaces in which to share his resources.

3.2.4 Activity Module

The activity module represents the processes and procedures done over time. At first, The activity representation in MEMORAE-core2 focused only on procedural activities in the real life such as buy activity, sell activity, and manufacturing activity. Meanwhile, to respond to the need for representing interaction activities in the virtual environment, MEMORAE-core2 model import PROV ontology [Belhajjame et al., 2017] and propose a specification of activity as seen in (Fig. 3.4).

An activity is something that occurs over a period of time and acts upon or with resources; it may include consuming, processing, transforming, modifying, relocating, using, or generating resources. Activities and resources are associated with each other in two different ways: activities utilize resources and activities produce resources. The integration of the activity module is as follows:

- mc2:Activity rdfs:subClassOf PROV:Activity
- mc2:InteractionActivity rdfs:subClassOf mc2:Activity
- mc2:ProceduralActivity rdfs:subClassOf mc2:Activity
- mc2:Activity PROV:utilize mc2:Resource
- mc2:Resource PROV:wasGeneratedBy mc2:Activity

the agent has a role in the activity:

- mc2:UserAccount rdfs:subClassOf PROV:Agent

- mc2:InteractionActivity PROV:wasAssociatedWith mc2:UserAccount (BY INFERENCE)

The specifications of mc2:InteractionActivity are as follows:

- CreateActivity: The activity of creating an original resource in the platform, e.g., creating a note;
- DeleteActivity: The activity of deleting a resource in the platform;
- ModifyActivity: The activity of modifying a resource in the platform;
- AccessActivity: The activity of accessing a resource in the platform;
- AddActivity: The activity of adding a resource in the platform which does not exist before, but is not created originally by the user who adds it;
- ShareActivity: The activity of sharing a resource in the platform, e.g., sharing with another group a document which is already added to the platform.

The creation by relation:

- mc2:Resource mc2:wasGeneratedBy mc2:CreateActivity

The addition by relation:

- mc2:Resource mc2:wasGeneratedBy mc2:AddActivity

The deletion by relation:

- mc2>DeleteActivity mc2:utilize mc2:Resource

The modification has two relations as we take into consideration the versioning of resources. Based on an old version of resource, a user modifies this resource by creating a new version:

- mc2:ModifyActivity mc2:utilize mc2:Resource

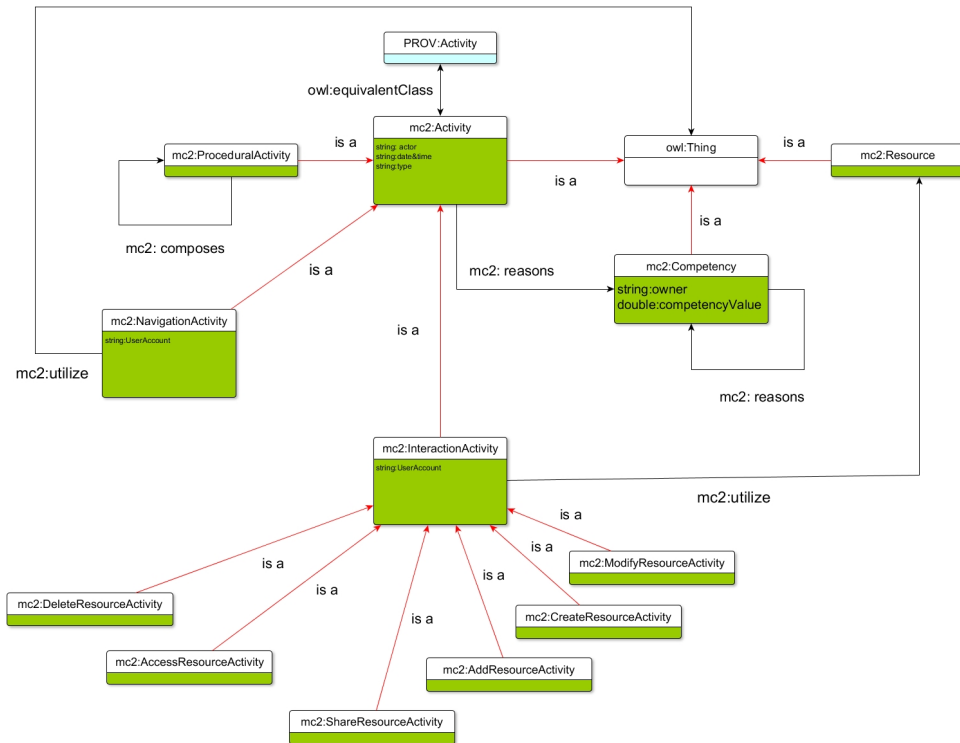


FIGURE 3.4: Activity module as a part of the whole MEMORAE-core2 model.

- mc2:Resource mc2:wasGeneratedBy mc2:ModifyActivity

The access by relation:

- mc2:AccessActivity mc2:utilize mc2:Resource

The sharing by relation:

- mc2:ShareActivity mc2:utilize mc2:Resource

Back to John story: *"John adds a document named 'Advanced Java' in his personal sharing space."*

John invokes an mc2:AddResourceActivity with his user account kb:JohnAccount:

- kb:AddAdvJava mc2:wasAssociatedWith kb:JohnAccount

This activity kb:AddAdvJava has effect on a resource kb:DocAdvJava:

- kb:DocAdvJava mc2:wasGeneratedBy AddAdvJava

The resource kb:DocAdvJava is indexed by kb:Indexkey1 which is about subject "Java" and visible in John's own personal sharing space:

- kb:Indexkey1 mc2:index kb:DocAdvJava
- kb:Indexkey1 mc2:aboutClass owl:Java
- kb:Indexkey1 mc2:isVisibleFor kb:JohnSpaceOfGroup

John shares it with his study group. Another member of the group, Jane, finds the document helpful and writes a comment "Very important for me!"

- kb:ShareAdvJava mc2:wasAssociatedWith kb:JohnAccount
- kb:ShareAdvJava mc2:utilize kb:DocAdvJava

The resource kb:DocAdvJava then is indexed by another indexkey kb:Indexkey2 which is about subject "Java" and visible in the public sharing space of the study group:

- kb:Indexkey2 mc2:index kb:DocAdvJava
- kb:Indexkey2 mc2:aboutClass owl:Java
- kb:Indexkey2 mc2:isVisibleFor kb:StudySpaceOfGroup

Jane now can add her comment as follows:

- kb:Jane mc2:hasUserAccount kb:JaneAccount
- kb:JaneAccount sioc:memberOf kb:StudyGroup
- kb:StudyGroup sioc:hasMember kb:JaneAccount
- kb:CreateAnnoAdvJava mc2:wasAssociatedWith kb:JaneAccount
- kb:AnnoAdvJava mc2:wasGeneratedBy kb:CreateAnnoAdvJava
- kb:AnnoAdvJava mc2:hasTarget kb:DocAdvJava

3.2.5 Vote Module

The vote as a resource is introduced by [Wang et al., 2016] to the MEMORAe-core2 model. Users have different preferences on resources for different purposes. They express these preferences on the resources by giving a value between 1 and 5, the higher the value, the more they appreciate the resource. The vote is modeled (Fig. 3.5), as a simple resource for mainly three reasons:

- Modeling Vote as a resource make it possible to index it by an index key that is visible in a certain sharing space;
- A vote is created by a user;
- Vote can further be used for reasoning the competency of a user who has created, shared or modified the voted resource.

Users vote according to the relevance and suitability of a resource on a subject in a group. Even resulting from a vote of the same user on an identical subject, the results can also vary for different sharing space, as the viewers in different groups have a different level of cognition. Moreover, each sharing space may have a different concept focus which also differentiates the vote.

The integration of vote in MEMORAe-core2 model results in the creation of the following triples:

- mc2:Vote rdfs:subClassOf mc2:SimpleResource
- mc2:Vote mc2:hasTarget mc2:IndexKey
- mc2:IndexKey mc2:index mc2:Vote

Now, as for John, *”John votes 3 out of 5 to ‘Advanced Java’ in his personal sharing space, as he thinks it is a good book but not suitable for his level.”*

As ‘Advanced Java’ is indexed by IndexKey1 in the sharing space kb:JohnSpaceOfGroup, this indexkey is the target of kb:VoteAdvJava1

- kb:Indexkey1 mc2:index kb:DocAdvJava
- kb:Indexkey1 mc2:aboutClass owl:Java

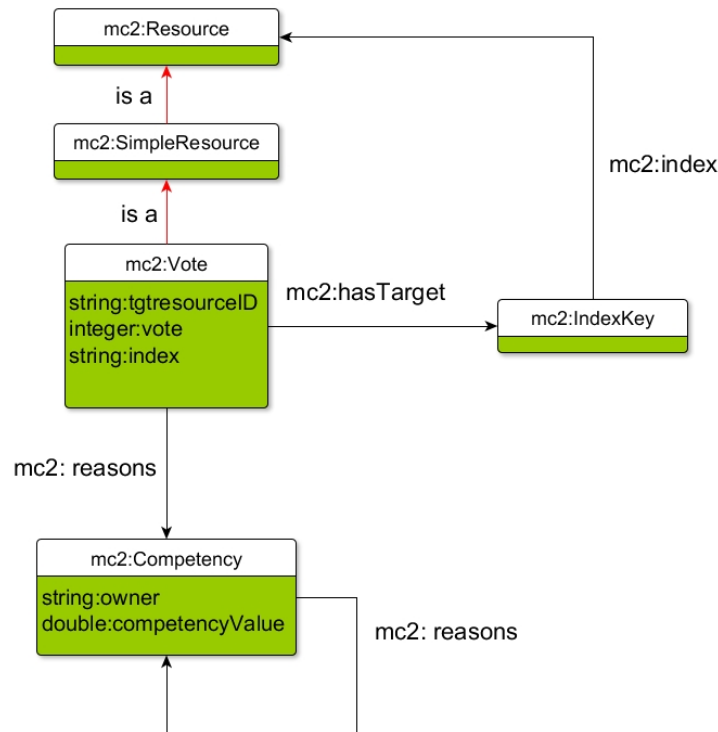


FIGURE 3.5: Vote module as a part of the whole MEMORAE-core2 model.

- kb:Indexkey1 mc2:isVisibleFor kb:JohnSpaceOfGroup
- kb:VoteAdvJava1 mc2:hasTarget kb:Indexkey1
- kb:CreVoteAdv1 mc2:wasAssociatedWith kb:JohnAccount
- kb:CreVoteAdv1 mc2:reateResource kb:VoteAdvJava1
- kb:VoteAdvJava1 a mc2:Vote
- kb:VoteAdvJava1 mc2:hasvalue "3"

The vote VoteAdvJava1 is indexed by kb:Indexkey3 which is about subject "Java" and visible in John's own personal sharing space. These properties are corresponding to the indexkey of resource that the vote aims at.

- kb:Indexkey3 mc2:index kb:VoteAdvJava1
- kb:Indexkey3 mc2:aboutClass owl:Java
- kb:Indexkey3 mc2:isVisibleFor kb:PeterSpaceOfGroup

"In the study group. John gives a 5 out of 5 vote to 'Advanced Java' in the public sharing space, as he thinks it is really useful to members of this group."

As 'Advanced Java' is indexed by kb:Indexkey2 in the sharing space kb:StudySpaceOfGroup, this indexkey is the target of kb:VoteAdvJava2. kb:Indexkey2 and kb:Indexkey4 thus are about the same class and visible in the same sharing space:

- kb:Indexkey2 mc2:index kb:DocAdvJava
- kb:Indexkey2 mc2:aboutClass owl:Java
- kb:Indexkey2 mc2:isVisibleFor kb:StudySpaceOfGroup
- kb:VoteAdvJava2 mc2:hasTarget kb:Indexkey2
- kb:CreVoteAdv2 mc2:wasAssociatedWith kb:JohnAccount
- kb:CreVoteAdv2 mc2:createResource kb:VoteAdvJava2
- kb:VoteAdvJava2 mc2:hasvalue "5"
- kb:Indexkey4 mc2:index kb:VoteAdvJava2
- kb:Indexkey4 mc2:aboutClass owl:Java
- kb:Indexkey4 mc2:isVisibleFor kb:StudySpaceOfGroup

3.3 Our MEMORAeSoIS Model

3.3.1 The Need for a Specific Model of SoIS

As we saw in the previous example, the MEMORAe-core2 model helps John to participate in a study group and share some resources, then other members of the group can vote on the shared resources. Also the interaction activities of users are traced (who did what and when?). Basically, this is collaboration among different users, and it is enabled by MEMORAe-core2 model (represents user accounts, resources, activities, etc.).

If we go back to the use case scenario presented in Chapter 1, we can see that the goal of John and his colleagues is to collaborate over resources they produce in the discourse of their work. The missing point here is that those resources are produced in different ISs. When John wants to share a document with his colleagues, add a new contact that he deems to be useful for others, or even share a simple general note, he has to store his resources within MEMORAe platform. The "Advanced Java" book

should be uploaded to the server of MEMORAe in order to be able to share it and index it. Now, what if John uses other systems to upload his files and documents like Google Drive. It is stated in the scenario that John uses many ISs to achieve his work. We can find a limitation in MEMORAe-core2 model in terms of representing resources coming from different ISs. Also, how do MEMORAe-core2 model allows interaction with such resources? i.e. indexing, sharing, voting, and commenting on external resources. In the light of this argument that MEMORAe-core2 model is not enough by itself to represent the SoIS, we move in this thesis to present our model for SoIS. As MEMORAe-core2 model proves its collaboration capabilities, we need to extend it further to support resources coming from different ISs in the environment of SoIS.

3.3.2 The SoIS Model

In the light of MEMORAe-core2 model, and the need for a semantic model representing the SoIS, this study presents a semantic model of the SoIS built based on semantic web standards.

The model is present in (Fig. 3.6). The SoIS model extends the MEMORAe-core2 model to allow for the proven concepts in MEMORAe-core2 to be used in the conceptualization of the SoIS. The legend in (Fig. 3.6) shows the different parts of the SoIS model. We can see the standard libraries of SOIC and FOAF being extended alongside the mc2 model. The SoIS prefix denotes the concepts that represents the aspects of the different types of systems that can be included in the SoIS, the different APIs that can be used to connect with external systems, and the different types of references that can link external resources to the SoIS.

We can continue the example of "John Doe" with the SoIS model. Here, John can use different ISs to produce resources before indexing and sharing the references of these resources. With this model we can allow John to find resources in different ISs, for example a wiki system, and import their references into MEMORAe. an illustration of a reference to an external resource looks like this:

- kb:WikiJavaIntroductionRef rdfs:literal kb:WikiJavaIntroductionID
- kb:WikiJavaIntroductionRef rdfs:literal kb:WikiJavaIntroductionTilte

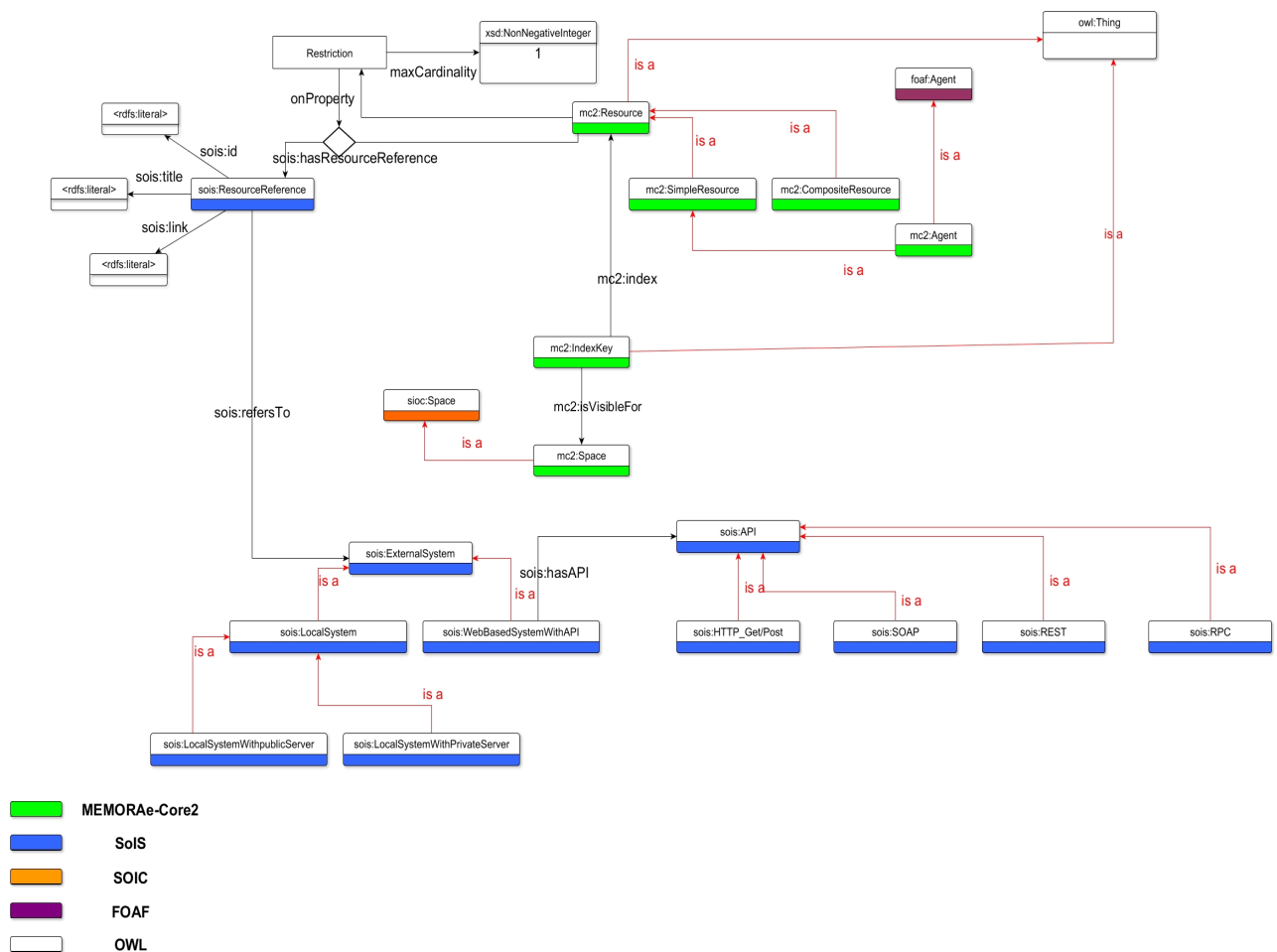


FIGURE 3.6: MEMORAE SoIS model.

- `kb:WikiJavaIntroductionRef rdfs:literal kb:WikiJavaIntroductionLink`

This reference refers to an external system like this:

- `kb:WikiJavaIntroductionRef sois:refersTo kb:TiddlyWiki`

The TiddlyWiki system is a subclass of an external system and has its own API. All the information related to this external system can be represented by our SoIS model as follows:

- `kb:TiddlyWiki a sois:WebBasedSystemWithAPI`
- `sois:WebBasedSystemWithAPI rdfs:subClassOf sois:ExternalSystem`
- `kb:TiddlyWiki sois:hasAPI kb:TiddlyWikiAPI`

- kb:TiddlyWikiAPI a sois:HTTPGetPost
- sois:HTTPGetPost rdfs:subClassOf sois:API

Then, this reference of a wiki page can be indexed and shared within MEMORAeSoIS as follows:

- kb:Indexkey5 mc2:index kb:WikiJavaIntroductionRef
- kb:Indexkey5 mc2:aboutClass owl:Java
- kb:Indexkey5 mc2:isVisibleFor kb:JohnSpaceOfGroup
- kb:Indexkey5 sois:hasResourceReference kb:WikiJavaIntroductionRef

The function of voting [Wang et al., 2015] can be extended from mc2 model so that users evaluate a resource by relevance of which it is indexed, and sharing space where the resource is visible. As shown in (Fig. 3.6), vote is a resource in the model of the SoIS. It is related with IndexKey by the relation hasTarget as shown in (Fig. 3.6).

The SoIS allows the users to interact with various heterogeneous resources coming from different Information Systems in many ways. The user can view the referenced resources, index the important ones, share them within different sharing spaces, annotate, comment and vote on them. An added value can be achieved by tracing the users' activities in the SoIS. The importance of these traces comes from their role in the reasoning process of the recommender system proposed by [Wang et al., 2015].

In the model of SoIS we can view the leader system as a knowledge base that handles organizing and sharing of resources from different Information Systems. MEMORAe-core2 model aims, by its design, to facilitate knowledge sharing and capitalization within those different systems. All types of resources can be indexed by a map of shared terminology that represents the concepts of interest for the user [Atrash et al., 2015]. Furthermore, the map defines a common reference shared between all users. The focus concept of the map is a concept in which the user is interested in. The shared resources are indexed by the concepts of the map. In this orchestration of SoIS, MEMORAeSoIS is introduced to new resources produced by Information Systems that reside outside its scope, hence the use of the leader system as it supports different types of social resources (wiki, forums, chat) and documentary resources (documents, images, web link). This constitutes an added value for the Information Systems comprising

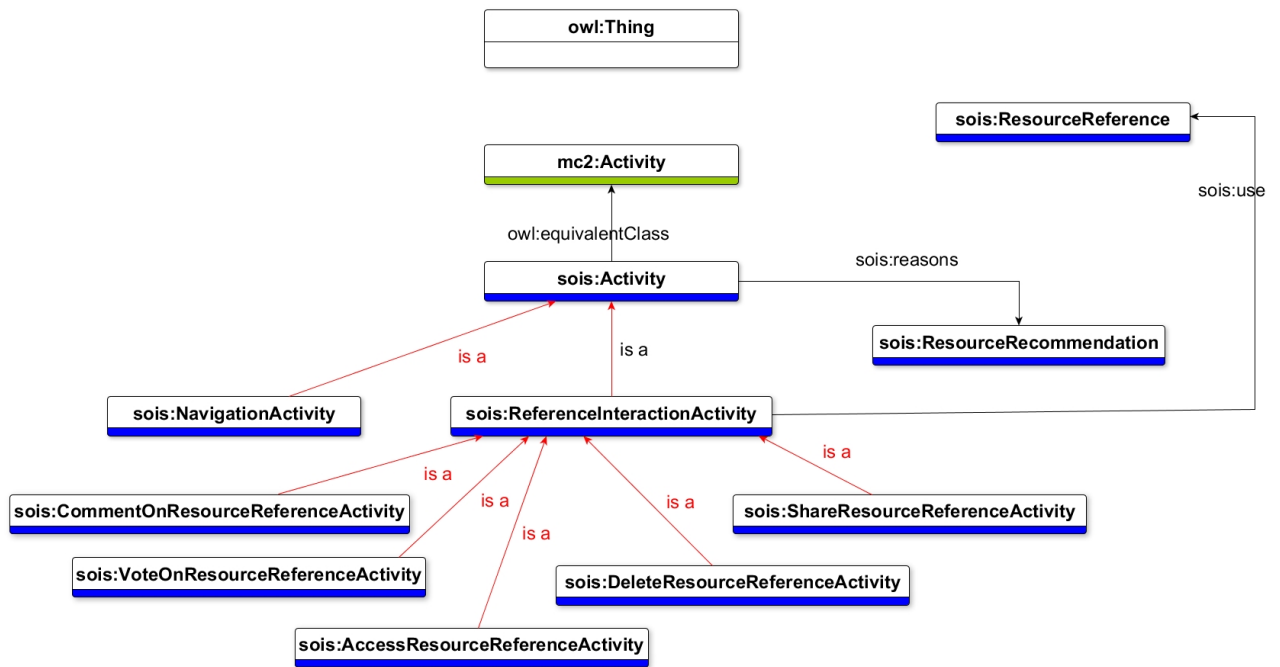


FIGURE 3.7: MEMORAeSoIS model.

the SoIS, as data produced from those systems is capitalized as knowledge within the leader.

The activities of users in the SoIS is traced and logged with the help of the "sois:Activity" concept. This concept is derived directly from "mc2:Activity". In MEMORAeSoIS users add, share, access, and delete the references of resources that come from different ISs. When these systems are operating separately we can not see the full scope of users' activity in all the ISs. Now, with the help of MEMORAeSoIS, we can record users' activities over resources of different ISs in one place. That is very important for the recommender system as now it gets its input for resources of different origins, and therefore, it can recommend resources to users from different ISs. The model of users' activities in the SoIS is presented in (Fig. 3.7).

The resources in the SoIS are stored in their respective systems. The SoIS only uses references of the resources and store in the knowledge base of the leader system (MEMORAe). As for the votes, comments, and users' activities, they are produced in the leader system and stored in its knowledge base as well.

3.4 Resources Recommender System Based on MEM-ORAEsoIS Model

The recommender system that recommends valuable resources to users is built based on our SoIS approach. This recommender system is modeled and realized as a project in a Master program at the University of Technology of Compiègne (UTC) and resulted in the following publication [Ameur et al., 2017a]. The recommender system depends on three entries: the user's profile, the resources which the recommender choose from, and the vote score.

For the recommender system we want to exploit the profile of the user in order to offer him/her good resources. The characteristics of the user concern the identity (name, surname, etc.), preferences (type, language, etc.), the state of knowledge of the user about the notions related to the training.

In the end, our model of the user in a learning ecosystem can be expressed by:

$$M_{user} = \{M_{id}, M_{pref}, M_k\} \quad (3.1)$$

M_{ID} : contains general information about the user, such as surname, first name, age, and his/her sharing spaces within the MEMORAEsoIS. The email address or user name with the password can be used to identify the user.

M_{Pref} : contains the preferences of the user concerning the preferred types of resources T (1 (text), 2 (video), 3 (audio)), the preferred format resources F (1 (PDF), 2 (Word), 3 (MP3), etc.), or the preferred language they use L (1 (French), 2 (English), etc.).

M_k : contains information characterizing the state of knowledge acquired by the user by specifying the level of knowledge (0 (no knowledge), 0.2 (very weak), 0.4 (low), 0.6 (medium), 0.8 (high), 1 (very high)).

Continuing with our scenario about Jhon Doe, the recommender system represents the information of the user John Doe inside the SoIS as seen in (Table. 3.1). Resources are well represented in MEMORAE-core2 model, but to truly capture the importance value of a resource we delve deeper and propose a model to measure the importance value of a resource. The model to measure importance level in a resource has three

TABLE 3.1: Example of the user John Doe representation according to the recommender system

	Attributes	values
M_{ID}	Name	John
	Last Name	Doe
	Age	18
	Account	john.doe@etu.utc.fr
	Password	xxxxxxx
	Sharing spaces	John, Study group
M_{pref}	T	weblinks
	F	html
	L	french
M_k	Java	0.6: Medium
	Pascal	0.8: High
	Data structure	0.4: Low

components:

$$M = \{M_{idr}, M_{KnowledgeRelevance}, M_{ObjectivPreference}\} \quad (3.2)$$

The M_{IDr} component describes the following elements: the title, the author, the training level, the date of creation, the date of sharing within a sharing space. The $M_{KnowledgeRelevance}$ component specifies the resource's indexes within a sharing space. A resource has a degree of relevance and a difficulty related to each of its indexes within a sharing space. The degree of relevance (1: strongly recommended, 0.75: recommended, 0.5: undecided, 0.25: weakly recommended, 0: not recommended) is calculated from the vote of users of the MEMORAeSoIS who are members of the group having access to the space of where the resource is visible. The difficulty specifies a level of accessibility for a given audience (0: low, 0.5: medium, 1: high) and is defined by the authors of the resource. The third component, $M_{ObjectivPreference}$, is used to classify resources into different categories based on their type T_r (1 (text), 2 (video), 3 (audio)), their format F_r (1 (PDF), 2 (Word), 3 (MP3), etc.), their language L_r (1 (French), 2 (English), etc.) and the percentage of adaptation to the different learning styles presented in the M_{pref} preference model.

According to our scenario earlier, Jane shared a document "Advanced Java" in the sharing space "Study group" indexed by the node "Java". Now, John shares another resource "Java Tutorial" which is a web link in the same sharing space under the same node. (Table. 3.2) shows how the recommender system gives score to both of these resources. Given that the recommender system is aimed to producing targeted

TABLE 3.2: Example of the scores of two resources according to the recommender system

	Attributes	Resource 1	Resource 2
M_{IDr}	Title	Advanced Java	Java Tutorial
	Author	Jane	John
	Create date	25-10-2017	25-10-2017
	Sharing date	25-10-2017	25-10-2017
	Sharing space	StudySpaceOfGroup	StudySpaceOfGroup
$M_{KnowledgeRelevance}$	Concept	Java	Java
	Degree of difficulty	1:High	0.5:Medium
	Relevance degree	0.25: Poorly recommended	0.75:Recommended
$M_{ObjectivPreference}$	T_r	Text	Hypermedia
	F_r	pdf	html
	L_r	English	French

resource recommendations, we propose to use the Pearson r correlation coefficient to analyze the similarity between the user model and the resource models. This coefficient is calculated from the quantitative information presented in the models (user, resources) and can take a value ranging from +1 (strong positive correlation) to -1 (strong negative correlation). Pearson Correlation Coefficient:

$$r_{xy} = \frac{\sum_{i=1}^n (X - m_x)(Y - m_y)}{\sqrt{\sum_{i=1}^n (X - m_x)^2 (Y - m_y)^2}} \quad (3.3)$$

Where

$$r \in \mathbb{R} \quad (3.4)$$

$$-1 \leq r \leq 1 \quad (3.5)$$

$$m_x = \frac{\sum_{i=1}^n X_i}{n} \quad (3.6)$$

$$m_y = \frac{\sum_{i=1}^n Y_i}{n} \quad (3.7)$$

n: the number of quantitative elements of the user or resource model.

X: a vector of size n which represents the different quantitative information of the user model.

Y: a vector of size n which represents the different quantitative information of the resource model.

TABLE 3.3: Example of input for similarity equation between the user John Doe and two different resources

	User: John X	Resource: Advanced Java Y1	Resource: Java Tutorial Y2
KnowledgeLevel/ DifficultyLevel	0.6	1	0.5
Relevance	1	0.25	0.75
Type	1	1	2
Format	2	1	2
Language	2	1	2

\mathbf{m}_X : the mean of the vector X; \mathbf{m}_Y : the mean of the vector Y.

(Table. 3.3) shows the input data for the similarity measures equation.

Applying (equation. 3.3), where n is 5:

$$m_x = \frac{0.6 + 1 + 1 + 2 + 2}{5} = 1.32 \quad (3.8)$$

$$m_{y1} = \frac{1 + 0.5 + 1 + 1 + 1}{5} = 0.9 \quad (3.9)$$

$$m_{y2} = \frac{0.5 + 0.75 + 2 + 2 + 2}{5} = 1.45 \quad (3.10)$$

That will make:

$$r_{xy1} = 0.3 \quad (3.11)$$

$$r_{xy2} = 0.9 \quad (3.12)$$

The result of computing the Pearson Correlation Coefficient r_{XY1} evokes a very strong correlation between the model of "John" and the model of the resource "Java tutorial". On the contrary, r_{XY2} evokes a rather poor correlation, the coefficient is less than 0.5. So the resource "Java tutorial" will be recommended to John by the recommender system because it is more adapted to him and it is better voted than the resource "Advanced Java".

3.5 MEMORAeSoIS Architectural Model

In this section we are going to present the architectural model of MEMORAeSoIS. Earlier we presented the semantic model of MEMORAeSoIS which helps in understanding the different elements and their relations in MEMORAeSoIS (resource, vote, user account, users' activities, index key, etc.). The architectural model serves as a blueprint for implementing the prototype of MEMORAeSoIS. It guides the efforts to move from a Digital Ecosystems towards a System of Information Systems with simplicity and ease by identifying the technical structure of the SoIS. The architectural model is responsible for linking different ISs with the leader system. It is the reference to go to when trying to expand the SoIS and include new ISs as it organizes the SoIS and encapsulates its components preparing for change to happen.

As seen in (Fig. 3.8), the SoIS will have access to resources coming from several Information Systems (System A, System B . . . etc.). These systems are working separately. Each of which has its own services and databases. The services of these systems are denoted as solid rectangles inside the system (Service 1A, Service 1B . . . etc.). Resources can be represented in different ways within different systems, thus, the SoIS might have trouble to access information. Therefore, there is a growing need for a solution to this issue. A solution to the problem of assuring interoperability within the SoIS is to control the communication medium among the systems. Two methods, outlined by [Bowen and Sahin, 2010], include:

- Creating a software model of each system, where the software model collects data from the system and generates the outputs.
- Creating a common language to describe data, where each system can represent its data such that other systems may interpret.

Due to overhead restrictions on architecture and a required common language, it is not often that individual software models are created for the various systems. Therefore, we follow the System of Systems Interoperability model (SOSI) presented in the previous chapter. In accordance to the SoSI, we achieve three levels of interoperability (programmatic, constructive, and operational) by following the semantic model and the architectural model of MEMORAeSoIS. The semantic model provides a distinct representation of resources while the architectural model unifies the communication between different ISs and the leader of the SoIS.

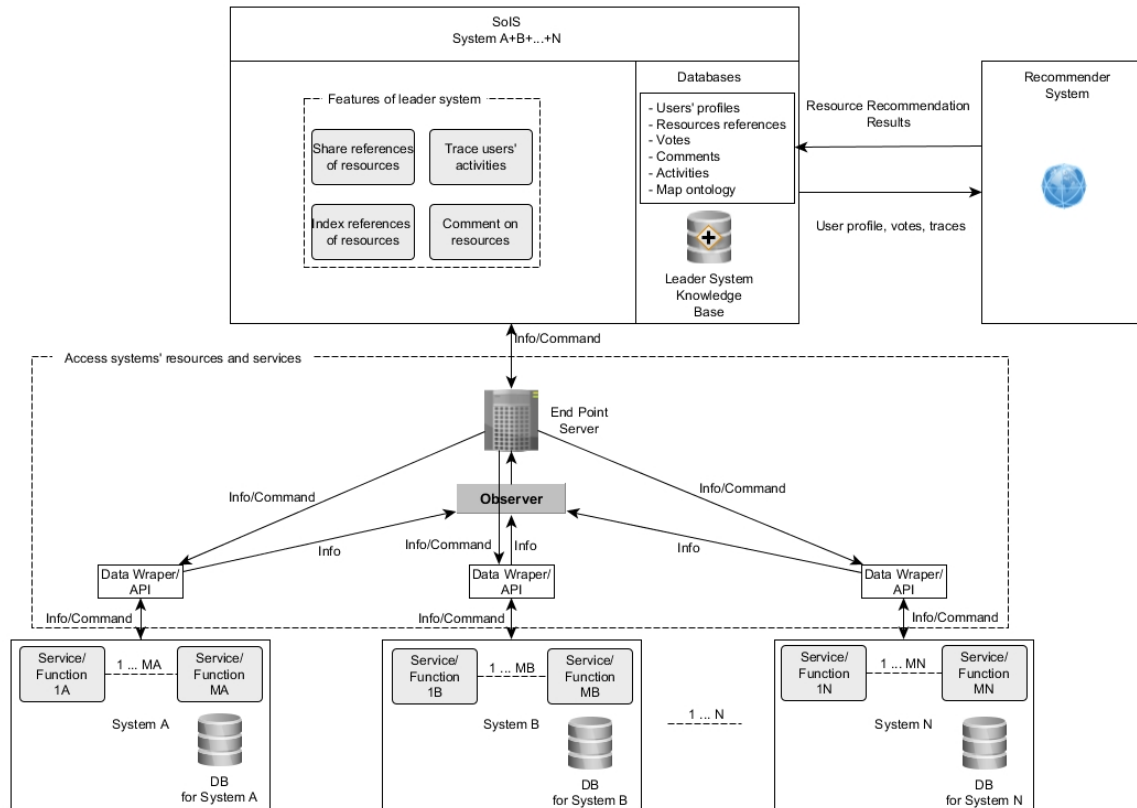


FIGURE 3.8: Architectural model of MEMORAeSoIS.

The architectural model shows three distinctive layers for the SoIS. The leader system is represented in the top layer as a group of services and a database. The services residing in the leader comes from MEMORAe approach. The middle layer is responsible for the communication between the ISs and the leader system. This layer is maintained with an endpoint server implementing an observer pattern to keep the resources up to date whenever there is change in the constituent ISs (new resources are added, modified, or deleted). In the third layer we can see the constituent ISs. Either the ISs has an API that allow for communication with the middle layer and the interrogation for resources, or we write a data wrapper that can get the resources from a dedicated ISs. If the ISs denies both solutions (No API and not accepting data wrapper), the system is considered a black box with no mean to communicate its resources to other systems, hence, it can not be added to the SoIS.

3.6 Summary

Based on the direction of this thesis we aim to move from a classical DE towards a SoIS that is more flexible to expand and provide the user with more functionalities (sharing resources, indexing resources, voting, commenting, tracing users' activities concerning resources from different ISs, etc.). From the leader/follower approach we defined two distinct concepts: the leader system, and the follower system. This is the cornerstone in our SoIS approach. For the Role of the leader system we investigated a model of knowledge management and collaboration called MEMORAe-core2. We concluded that this model can be used for building the leader system of the SoIS, and to provide guidance of how to model the SoIS itself. Finally, we presented our semantic and architectural model of the SoIS that highlighted our approach for moving forward towards a SoIS. The semantic model of the SoIS presented the different elements and concepts that play main role in realizing a collaborative environment as the SoIS. The architectural model showed how the SoIS can include different ISs (one is the leader system while the others are designated as followers). It also showed that the follower systems can be autonomous as long the leader system can have a way to reference their resources. All the functionalities of the SoIS can then be supplied by the leader system.

Chapter 4

MEMORAeSoIS Prototype

4.1 Introduction

In this chapter we present the generic prototype of MEMORAeSoIS built in respect to the semantic model and based on the architectural model. MEMORAeSoIS has different applications that all depends on this generic prototype. These applications varies according to the ISs constituting MEMORAeSoIS. Hence, we can say that there are several applications for MEMORAeSoIS prototype. When we speak in this chapter about MEMORAeSoIS prototype we mean to focus on the generic functionalities rather than the different applications. The prototype aims not only to aggregate resources from different ISs, but also to provide an added value to the user. The added value comes from the leader system as it provides the user with the ability to search for, index, share, vote, comment on resources, and on top of that, the ability to trace users' activities and provide recommendation to users. This chapter is organized as follows: section 4.2 will present the technical infrastructure that represents the digital environment in which MEMORAeSoIS operates. Then, in section 4.3, the implementation of MEMORAeSoIS prototype is shown. After that, different applications of the prototype are shown in section 4.4. Finally, the summary of this chapter is presented in section 4.5.

4.2 Infrastructure of MEMORAeSoIS

The infrastructure that holds MEMORAeSoIS as part of it is presented in (Fig. 4.1). The functionalities are developed from the MEMORAe-core2 model formalized in the owl language and deployed in the virtuoso 7.x triple store. The communication with the base of triples is done by means of an API which was developed in PHP by [Atrash, 2015]. Our contribution in this infrastructure is denoted with a star.

The functionalities illustrated in (Fig. 4.1) varies from front-end to back-end. There are the management and access to resources (back-end server side) and the visualization and manipulation of resources and the use of the map (navigation or map search) which is done at the front-end client level.

A mobile client (MEMORAe Note) dedicated solely to note-taking and sharing within the MEMORAe platform and two MEMORAe web clients: an integrated web client and a SoIS web client have been developed depending on this infrastructure.

Both clients, integrated and SoIS, share a number of features:

- Navigation within a knowledge map of shared terminology illustrating the concepts of interest for the collaborators;
- The visualization of sharing spaces in parallel facilitating the transfer of resources from one space to another and therefore facilitate sharing resources;
- The possibility of viewing all the resources indexed by a concept of the map: the focus concept of the map; these resources can come from chat, wiki, calendar, etc.
- The storing of web links within virtuoso;
- The creation of a vote within virtuoso on the relevance of a resource with respect to an index key and a sharing space.
- The annotation of resources;
- The creation of bookmarks.

The main difference between the two web clients, integrated MEMORAe and MEMORAeSoIS, is in the way of creation and storing their resources. The integrated web

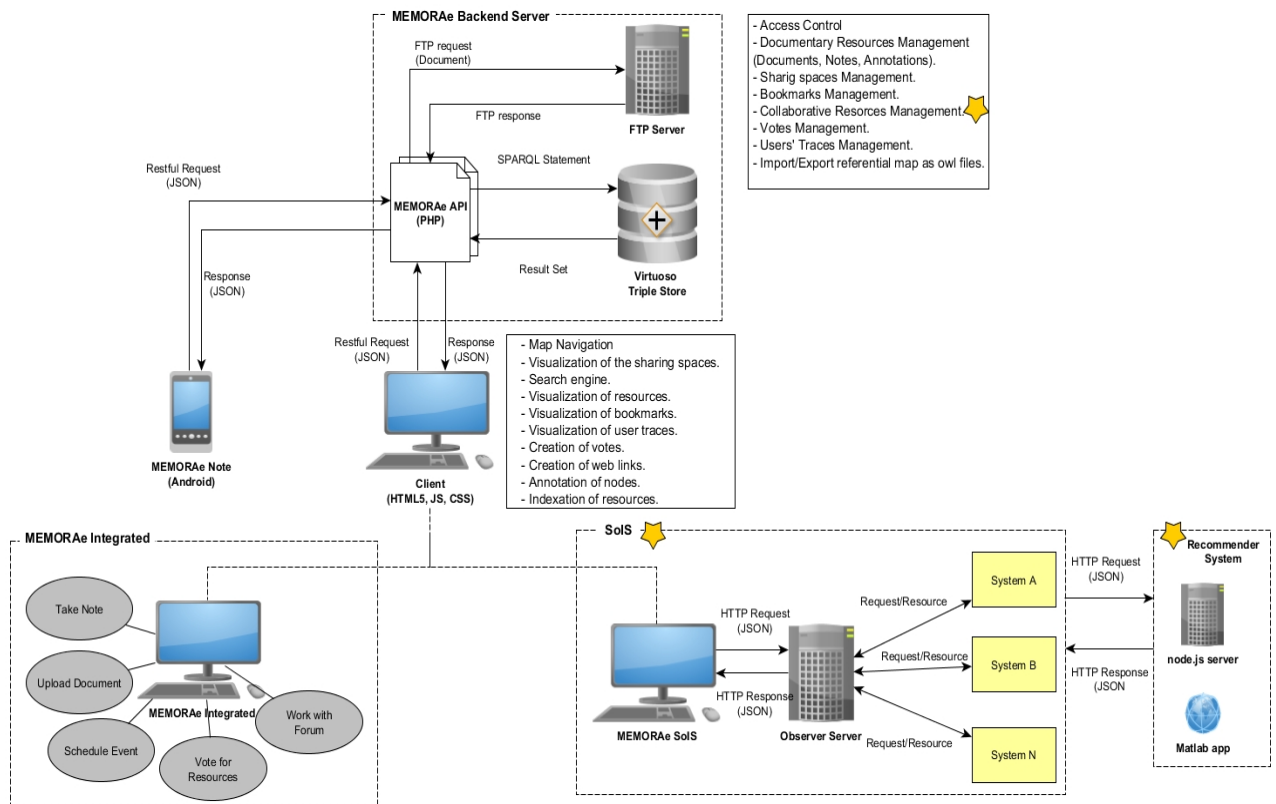


FIGURE 4.1: The infrastructure of MEMORAe platform.

client can create and store social resources (note, resource annotation, question, answer, contact, event, etc.) within virtuoso. Also, upload a document and store it within a FTP server. It also allows the user to index these resources using a map of shared repository.

The MEMORAeSoIS web client makes it possible to link to different autonomous external IS (constituent systems) in order to capitalize the resources they can produce (Tiddlywiki, twitter, google contact, OneNote, etc.). The SoIS web client is a centralized system linked to the observer server. The latter is in turn linked to constituent ISs with an API or "data wrapper". It is responsible for managing the connection with constituent systems and for querying these systems for resources. The reference to access a resource is then indexed by means of an index key belonging to the map of shared terminology. Also, MEMORAeSoIS is associated with a recommender system that implements its algorithm with Matlab. The Recommender system is also developed with node.js dependency to allow for communication with the leader system of MEMORAeSoIS.

The features of the server concern:

- The organization of documentary and social resources around the cartography of knowledge; different views of resources according to their semantic description: any resource can be indexed by its content (the concepts it processes) or its container (author, date of creation, etc.);
- Different views of the resources within sharing spaces according to the access rights of the user: a private space (individual) and one or more sharing spaces (an associated space per user group);
- The modeling of collaborative resources (semantic forum, semantic chat, semantic wiki, semantic agenda, etc.); the content of these resources is itself accessible according to different points of view;
- Management of the traces of the activities carried out in a sharing space by a user;
- Search engine;
- The import / export of a common repository represented in OWL format.

4.3 Prototype Implementation

In this section we present the prototype of MEMORAeSoIS. There are two interfaces for the prototype: version 1 (Fig. 4.2) and version 2 (Fig. 4.3). The main difference between the two versions is the interface design. In terms of implementation and functionalities the second version includes the functionality to trace users' activities within the SoIS and the resources recommender system. The reason we made a new interface is that we were looking for more flexible and interactive presentation for the components of the prototype.

Currently, we are at version 2 of the prototype of MEMORAeSoIS. The first version was developed one year apart from the second to test our approach with the student at the University of Technology of Compiègne (UTC). The main interface of MEMORAeSoIS v1 is shown in (Fig. 4.2). The main parts of this interface are: the work space panel, the open sharing spaces, the map of shared terminology, and the panel to access external systems.

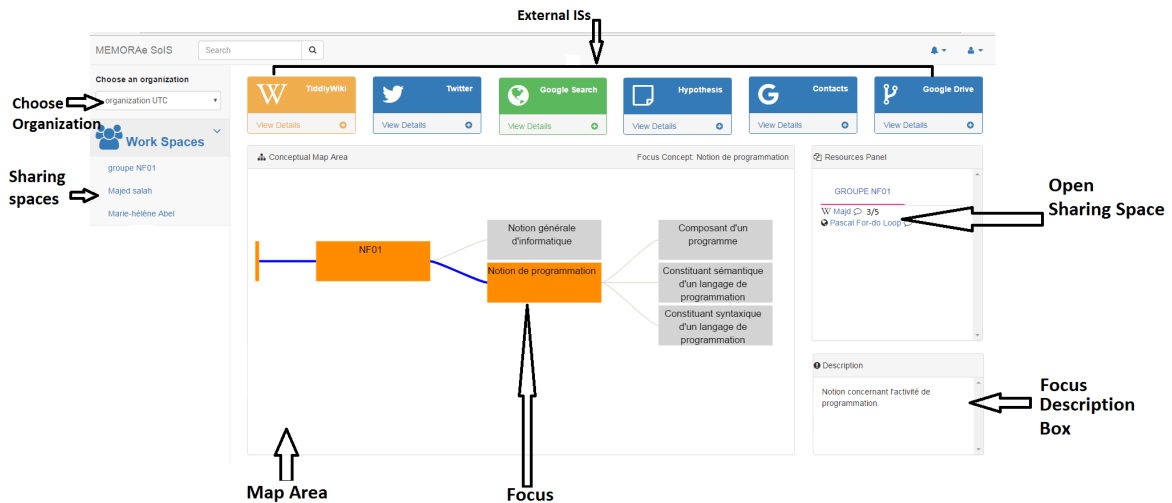


FIGURE 4.2: The main interface of MEMORAeSoIS v1.

The map is a graphical representation of the shared terminology of the chosen organization. The user can navigate this map and select a focus node (by clicking on a node). This node then takes on the status of active index, which means it will be the node considered as the index key when viewing the resources in the sharing space.

The sharing space contains the heterogeneous resources shared by the members of this space. The same resources can be found in different spaces as the user might share the resources in them. Nevertheless, each resource is stored in one place as a single instance but might be referenced by multiple sharing spaces.

Each user has at least two sharing spaces; one personal sharing space accessible only by the user himself/herself and another global sharing space shared by all the users in the organizations. Other sharing spaces can be found that contain different members of the organization.

In (Fig. 4.2) we see the most recent version of MEMORAeSoIS main interface. We can spot the changes that took place in the placement and organization of the main components of the interface. The map area is bigger with the new interface. The open sharing spaces can now be viewed together in parallel, and we have the capability to move the sharing space around as we work with different parts of the map. Alongside the resources in the sharing space, we can see the history and the resources recommendation as well. Also, the description box is no longer fixed in its place as we can drag it and move it around now.

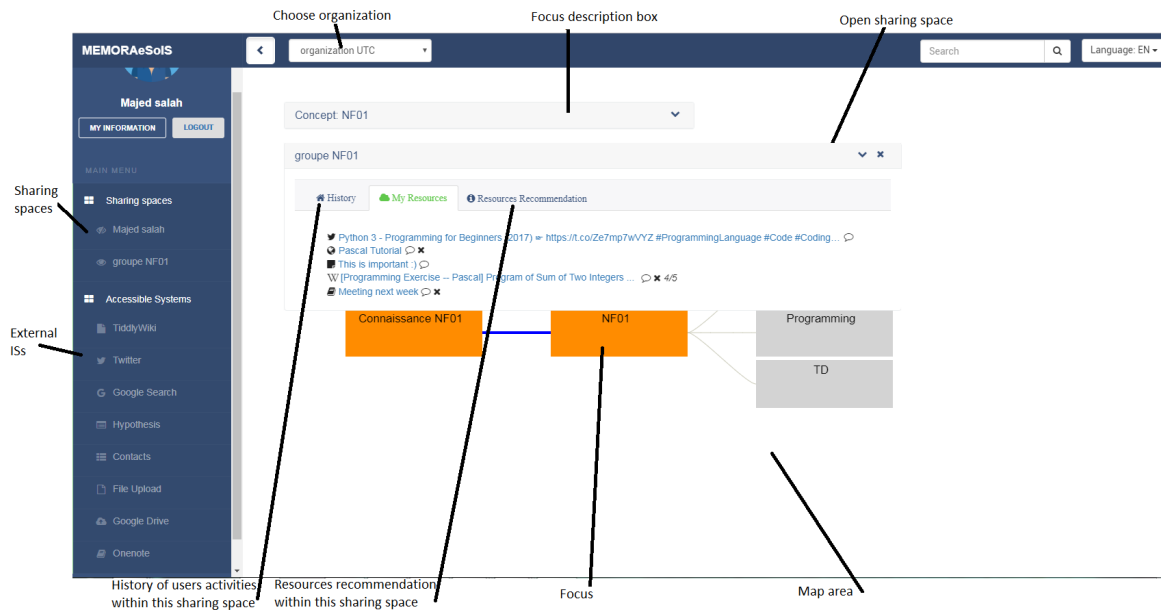


FIGURE 4.3: The main interface of MEMORAeSoIS v2.

The implementation of the prototype follows the semantic and architectural model of MEMORAeSoIS. The three layers of the architectural model are:

- The first layer (Top): This layer is the representation layer. It contains the leader system comprised of an API, a database, and an interface.
- The second layer (Middle): This layer is the communication layer. It contains the server responsible for the communication lines between the leader system and the follower ISs.
- The third Layer (Bottom): This layer is the Constituents Layer. It contains the constituent ISs following the leader system in the SoIS.

The top layer of the model represents the leader system and its interface with the users. The leader system itself has three parts. The first is the visual interface which is a web application developed using HTML5, Javascript, AngularJS, and CSS3. The second part is the leader system API (MEMORAe API). This API is developed using PHP5.6 and it is responsible for all the functionalities available in the leader system. MEMORAe API consists of services available through a restful API. These services are:

- CheckAccess service: responsible for login process.

- User Service: responsible for storing and providing users information.
- Graph Service: responsible for providing the map of shared terminology for an organization.
- SoISResource Service: responsible for indexing, sharing, voting, commenting, storing and providing the references of external resources (resources coming from different ISs).

MEMORAe API is connected to the third part of the leader system, which is the triple-store database. The database management system that we choose is Virtuoso7. We use the database to store triplets representing our semantic model.

The middle layer in the architectural model is the communication layer. It is responsible for maintaining the link between the leader system and the rest of the external ISs (the followers). This middle layer is a Java server built using Spring boot framework. We call it SoIS API to distinguish from MEMORAe API as each has a distinctive purpose (MEMORAe API is the API of the leader system that is responsible for its services like indexing, sharing, login, etc., while the SoIS API is responsible for the communication between the leader system and its follower ISs). In this server we manage the keys and tokens for the different APIs of the external ISs. It is built as a set of controllers and services where each service represents a restful endpoint that can be requested by the leader system. Each service is paired with a controller that implements the functionality of the service. For example, the leader system requests the list of wiki pages available in the TiddlyWiki system through a service in this SoIS API, then the service rely on the controller to establish the request for the list of wiki pages. Also, the SoIS API implements an observer pattern to check for updates in the external system periodically and notify the leader system only when there is a change in the external IS using a websocket protocol. This will allow the leader system to be up-to-date with the changes in the external ISs without the need to occupy the communication lines full-time. Mainly the changes that we monitor are adding or removing resources from an external IS. The SoIS server is important for including new IS as a constituent in MEMORAeSoIS. The new API key or token of the external IS along with its requests schema should be added to the SoIS server to allow for automatic communication with the external IS from this point forward.

A detailed user guide for the MEMORAeSoIS prototype is provided in Appendix [C](#)

4.4 Applications of the Prototype

In this section we introduce different applications for the MEMORAeSoIS prototype. As illustrated in earlier chapters, the SoIS model is based on MEMORAe-core2 model that distinguishes two levels of modeling: domain ontology, and application ontology. The domain ontology concerns the collaborative aspects of the model. The application ontology concerns the knowledge representation inside an organization. For example, if we apply MEMORAeSoIS in an industrial organization, the map of shared terminology (application ontology) that is used to index the resources should be customized and tailored to fit the organization's need and capture its knowledge by providing the right nodes to index the different resources. In another case, a university applying MEMORAeSoIS will also require to have a different map (application ontology). Also we should take into consideration that different organizations use different ISs and produce various amount of resources. That means we have to consider using different systems for different applications of MEMORAeSoIS. The flexibility of adding ISs to the orchestration to MEMORAeSoIS is possible thanks to the SoIS model and architecture, and having MEMORAe approach as the leader system to facilitate collaboration and resources indexing and sharing.

4.4.1 Web-based Information Systems with open APIs

The constituent ISs in this application are all web-based ISs with open API that allows for requests over HTTP protocol. These systems are: TiddlyWiki, Twitter, Google Search, Youtube, Hypothesis web annotation tool, Google Contact, File Upload, Google Drive, and Microsoft OneNote. These systems are chosen to be added to MEMORAeSoIS based on the type of resources they produce and their compliance to our architectural model.

The purpose of each system is illustrated as follows:

- TiddlyWiki: A system to create and organize personal wiki pages.
- Twitter: A system to search for tweets by hashtags within the Twitter social network.
- Google Search: A system to allow web search (powered by Google), and to add web link.

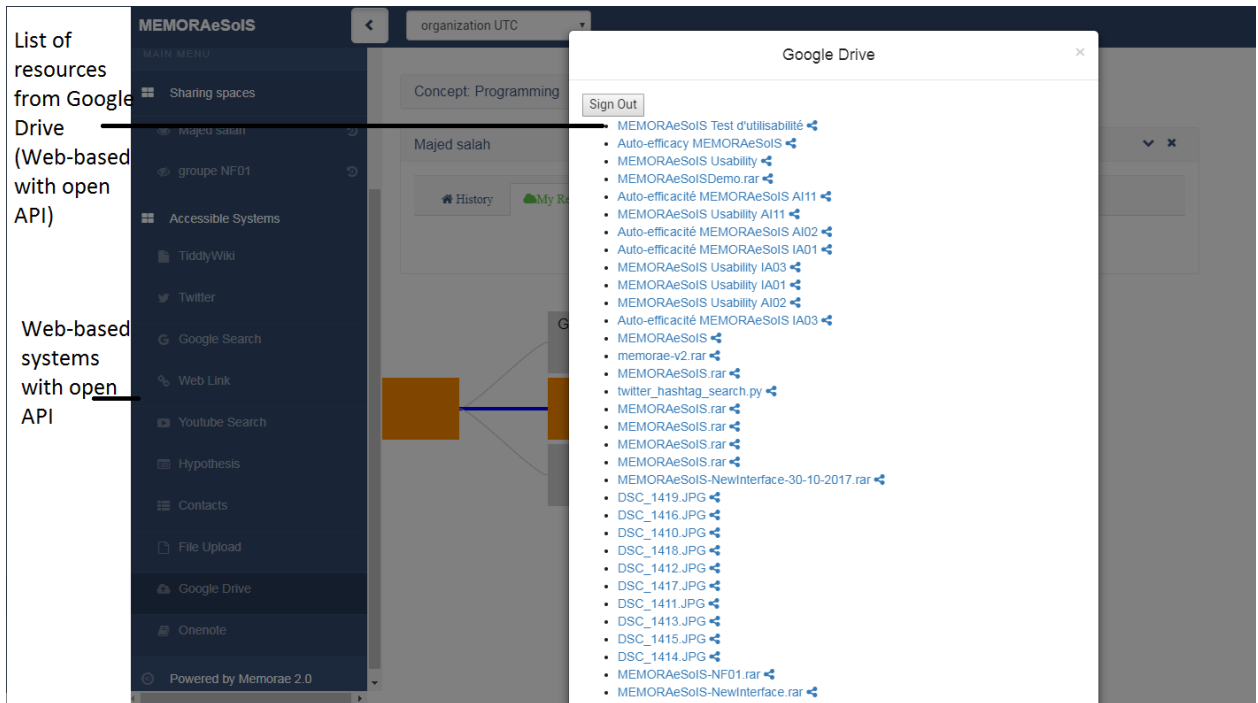


FIGURE 4.4: The list of resources from Google Drive (A web-based system with open API).

- Youtube: A system to publish and broadcast videos.
- Hypothesis: A system to annotate parts of web pages.
- Google Contacts: A system to get and view all Google contacts of the user.
- File Upload: A system to upload files from the local computer to the FTP server.
- Google Drive: A system to upload documents, share them with others, and store them in the cloud.
- Microsoft OneNote: A system to take notes and organize them in notebooks using different platforms (mobile, web).

The users of MEMORAeSoIS application for web-based systems with open API can access the resources of external web-based systems as shown in (Fig. 4.4)

4.4.2 Standalone Application with Closed Internal Server

Experts deal with many Information Systems in order to exchange their ideas and expertise, one of these systems is the brainstorming platform dedicated to archive and visualize information related solely to brainstorming sessions.

As a stand-alone IS that encourages collaboration on projects with innovative dimension, the ECOPACK brainstorming platform (realized as part of ECOPACK project funded by ANR project ANR-13-ASTR-0026) is interested in new forms of collaborative work enabled by a socio-technical computer environment including various devices (tablets, touch screen boards, smartphones, PC).

The objective is to offer a brainstorming platform accessible to each participant in the brainstorming sessions. Participants will use other ISs and need to be able to share their resources to collaborate. Therefore we link the ECOPACK brainstorming platform with MEMORAeSoIS where each participant is a user and each collaboration group is identified as a sharing space. Collaborative use of the brainstorming platform will itself produce specific resources that need to be capitalized in the same way as any other resource in the MEMORAeSoIS. Capitalizing the traces of interactions is also desirable in order to exploit them in justifications for decision-making.

The ECOPACK brainstorming digital platform is developed on the premises of a Digital Ecosystem capable of meeting the needs of innovation and strategic analysis of experts groups. The technical objectives of the ECOPACK brainstorming platform are as follows:

- Define a multi-user computer platform incorporating several types of devices (tablets, smartphones, PCs) for different forms of collaboration.
- Define collaborative applications accessed from different devices. Each user will benefit from different types of interaction and activity and will be able to exploit his/her own resources to collaborate. Applications developed can be synchronous, asynchronous, co-located and/or remote.

ECOPACK brainstorming platform is a set of heterogeneous data grouped as items, presented and gathered by a main module. The main module is responsible for providing a dynamic representation of the data as a graph that allows the interpretation by experts. It is essential to differentiate between the graph in the ECOPACK platform

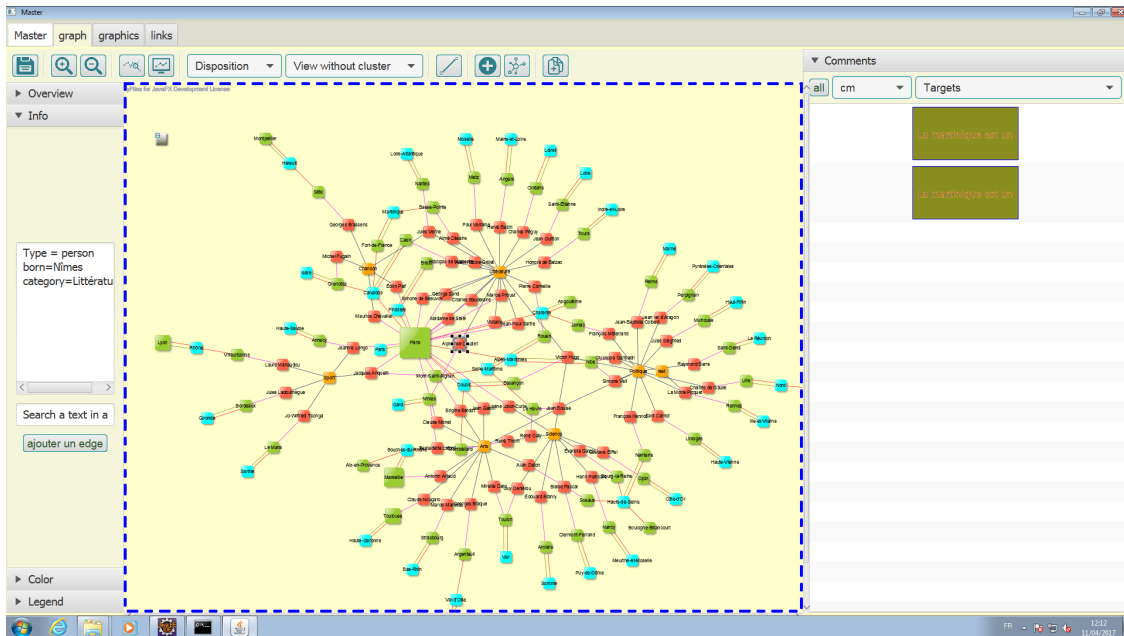


FIGURE 4.5: The main module of the ECOPACK brainstorming platform.

and the map in MEMORAe-core 2. The graph in the first one is merely a product of a visualization tool to represent data under discussion for brainstorming sessions, while in the latter, the map represent shared terminology among collaborators used to index heterogeneous resources that share the same target. Work is divided into work sessions. Participants in work sessions are permitted to send comments on the displayed data by the additional modules. The schedule module provides a representation of a small area of information visible on the main module. (Fig. 4.5) shows the main module of the ECOPACK brainstorming platform [Gouider and Abel, 2017].

The users of MEMORAeSoIS who are part of the brainstorming sessions can use the SoIS to access the resources produced in ECOPACK as seen in (Fig. 4.6). The resources that we query from ECOPACK platform are the projects and their items. The items are the reports produced inside those projects and the comments that are created during the brainstorming sessions. Each item has its meta data (creator, creation date, and target). The SoIS brings the meta-data along with the items in order to give the user of MEMORAeSoIS a better understanding about these items. The user can now find items from ECOPACK brainstorming platform indexed with a wiki page and/or weblink, all under a certain subject (node in the map of MEMORAeSoIS). This can help experts to further discuss the subject in depth.

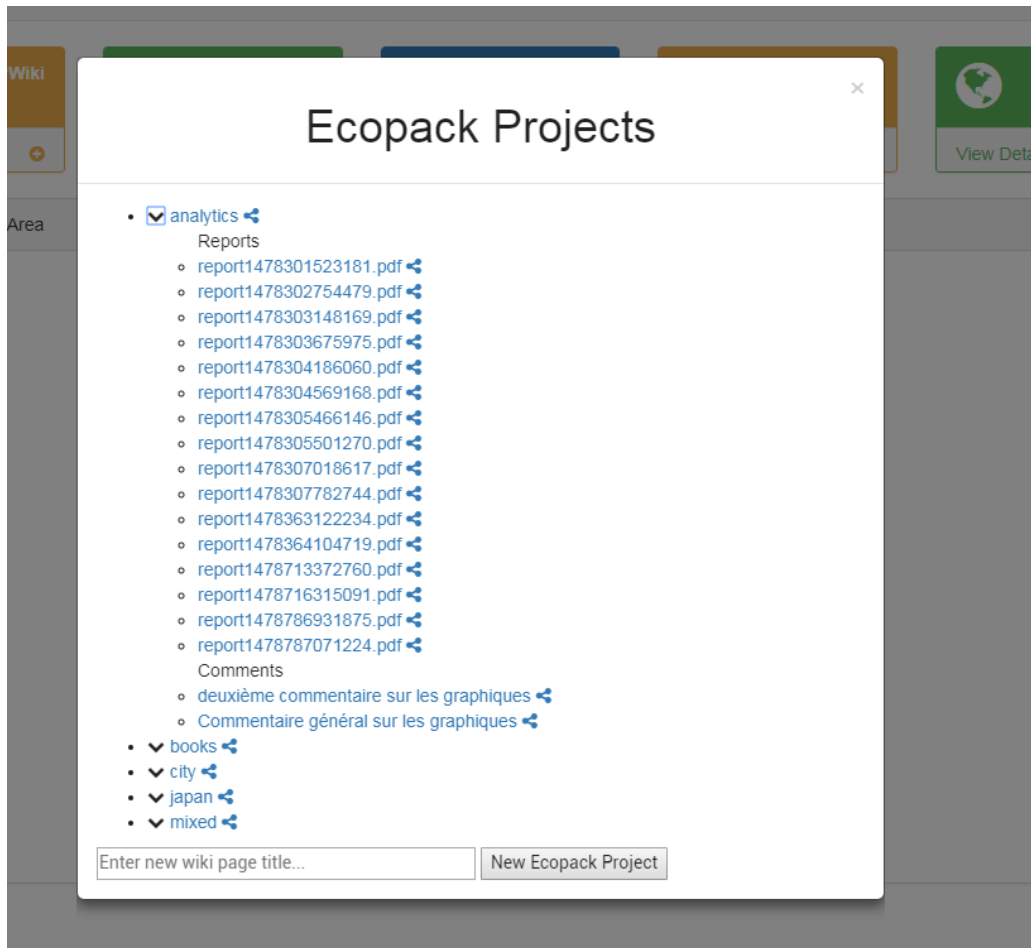


FIGURE 4.6: Accessing ECOPACK projects and their items from MEMORAeSoIS.

4.4.3 Standalone Application with Server Open for External Requests

Several other adaptations of MEMORAeSoIS took place throughout the period of our research.

The prototype for PLM Systems (Product lifecycle Management) aims to enable users to seamlessly access heterogeneous and distributed resources of PLM systems. PLM is *"a product centric–lifecycle-oriented business model, supported by ICT, in which product data are shared among actors, processes and organisations in the different phases of the product lifecycle for achieving desired performances and sus-tainability for the product and related services"* [Terzi et al., 2010].

PLM data volume and the associated evolution require the control of their consistency throughout the product life cycle. For example, product bill of material (MBOM)

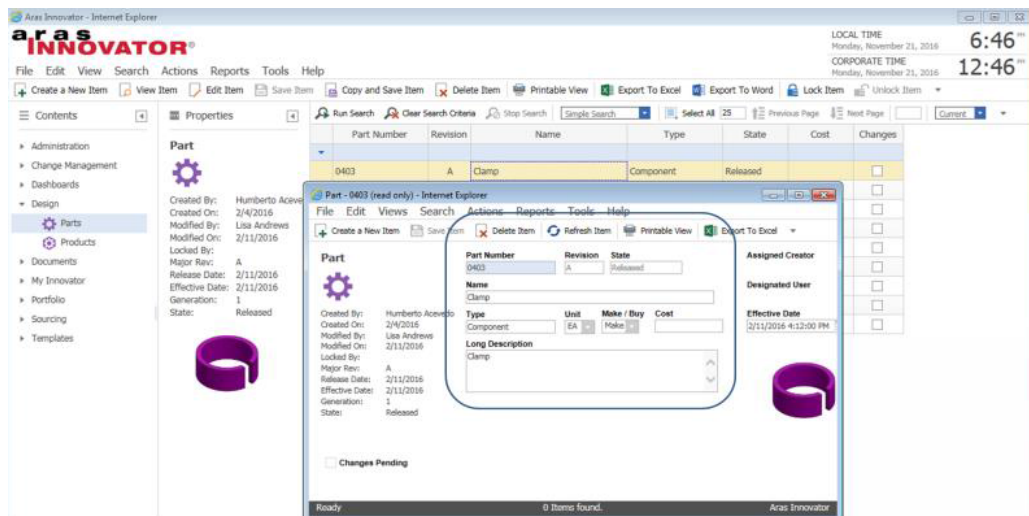


FIGURE 4.7: Search for items in Aras Innovator.

generation is based on design nomenclature (EBOM). This is generated by PLM application while the MBOM is generated by ERP application. These two nomenclature are strongly linked and without communication between ERP and PLM, the company has to manage the mapping manually between these BOM. This may lead to errors and a loss of time for the business actors. It is necessary thus to be able to automatically generate the MBOM from the EBOM [?].

Addressing the technical aspects is the first step to guarantee the interoperability between PLM systems and MEMORAeSoIS. The first implementation was carried out to test the feasibility of the connection between Aras¹ and MEMORAeSoIS. The objective is to test requests on the ARAS server in order to retrieve information about the resources and make them accessible in MEMORAeSoIS. The user specifies through the MEMORAeSoIS platform the resource to query for, for example: part, BOM, workflow, etc. (Fig. 4.7). These keywords are sent from MEMORAeSoIS to the ARAS server to retrieve the requested resource. Upon receiving the data, the Aras server converts them into JSON format so that they can be made visible and thus readable by MEMORAeSoIS. (Fig. 4.7) shows an example of the description of the "Part" entity in ARAS while (Fig. 4.8) shows its description in MEMORAeSoIS.

¹A system that is based on the Microsoft .NET Framework and SQL Server. It is used for product lifecycle management (PLM), advanced product quality planning (APQP), lean product development, product quality control, collaborative product development and new product introduction (NPI). <http://www.aras.com/>

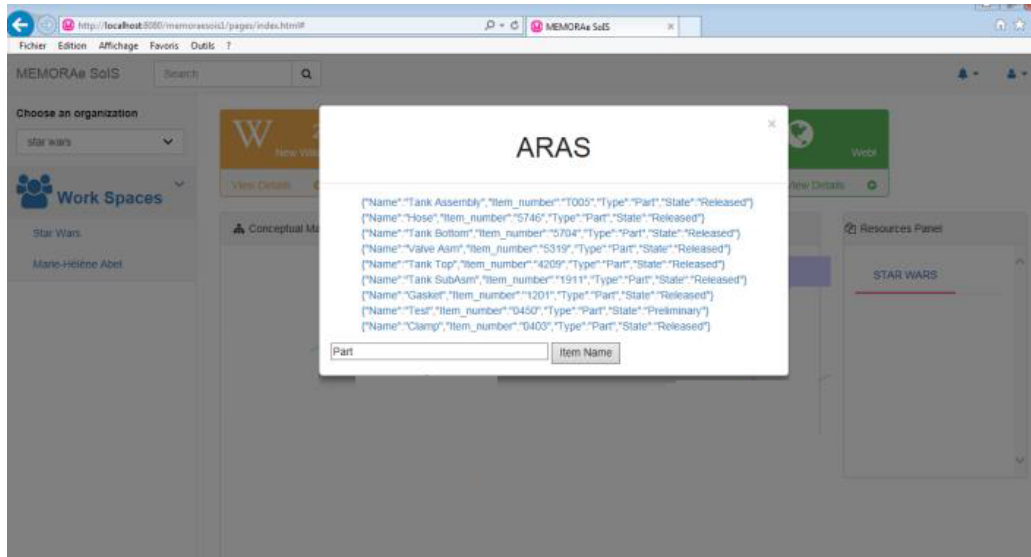


FIGURE 4.8: Description of the "Part" resource of Aras Innovator in MEMORAe-SoIS.

4.4.4 Discussion

Our work in this thesis addresses the issue of helping users from different domains and backgrounds dealing with overwhelming amount of resources coming from different Information Systems that the users work with regularly. The goal is to save the users from the effort of querying each system separately looking for useful and important resources. For that reason, we chose to build a DE using SoIS approach and adopt the MEMORAe-core2 model for collaboration and resource management for the leader system in the orchestration of the SoIS. Finally, we realized the prototype of MEMORAeSoIS.

The core functionalities of MEMORAeSoIS are indexing, sharing, commenting, tracing users' activities, accessing resources, and voting for resources. These functionalities apply to all kind of heterogeneous resources managed by MEMORAeSoIS. However, the resources themselves are different as they come from different Information Systems. In that sense, the domain of application for MEMORAeSoIS depends on the type of resources presented within its constituent systems. For example, if we are in the domain of e-learning, the Information Systems and their resources should revolve around this domain.

The link between the leader system and the constituent systems of MEMORAeSoIS is implemented based on the architectural model. In the applications presented earlier

in this chapter; Web-based application (Application with UTC students), stand-alone application with internal server (ECOPACK), and stand-alone with server open for external requests (ARAS), are all connected to the leader SoIS regardless of how they make their resources available for requester. The link is transparent for the user and easy to maintain for the developers thanks to the well established architectural model. This has given us flexibility when deciding to incorporate a new ISs in MEMORAeSoIS.

MEMORAe-core2 model has proven its usability as the basis of SoIS model. The representation of resources, users accounts, and different collaborative aspects had impact on the way we modeled the SoIS. The MEMORAe-core2 model allowed us to extend it to cover the aspects that we need in the leader system of the SoIS. This finally helped us in realizing the prototype of MEMORAeSoIS which we used in different applications.

Also, this work has some limitations. They are mentioned as follows:

- Most of the maps used so far for different organizations in MEMORAeSoIS are simple maps that contains tens of nodes. But there will be a need to use more complex maps with more nodes. This will make it hard for the user to navigate and view the map properly.
- Regarding the information flow between the leader system and the other constituent systems, information marches from the constituent Information System to the leader system as references of resources only. The leader system does not have a global view on the information of its constituent systems. For the moment, it only needs a reference of the resources residing in the constitute system to index it based on a map of shared terminology. It would be a good practice to discuss the possibility having a global view of the constituent systems within the leader system of the SoIS. This, however, will increase liability over the observer server responsible for this kind of communication.
- In some cases, the resources coming from an IS compose a very long list. For example a user might be using Microsoft OneNote and has hundreds of notes stored in his/her account. Their is no way to filter this content in the leader system. Once the user connects and tries to access the resources, a long list of resources will appear and waste the user's time while looking for relevant resources to index and share them.

4.5 Summary

In this chapter we viewed the technical infrastructure for MEMORAeSoIS prototype. We looked into the back-end server structure that supports the MEMORAeSoIS client along with other clients (web and mobile). We also compared the functionalities of the different clients that depend on the back-end.

After having a wider view of the technical environment of MEMORAeSoIS web client, we looked into the main functionalities provided by the prototype. We viewed the first version and the second and recent version. Then we proceeded to highlight the applications of MEMORAeSoIS prototype. These applications vary from web-based Information Systems with open API, to standalone applications with closed internal servers or with open servers for external requests. We introduce these different applications as an indicator for the wide range of possibilities that could be maintained with MEMORAeSoIS. Changing the ISs that composes the SoIS based on users' requirements can change the user experience and provide users with the proper resources they need to work with. Having a semantic and architectural model for the SoIS Allowed for such flexibility in including new ISs in the orchestration of the SoIS.

We mainly viewed three applications of MEMORAeSoIS: Firstly, the one tested the students at UTC where MEMORAeSoIS serves as a learning ecosystems. We also had good feedback from students about their experience. Secondly, we viewed ECOPACK brainstorming platform as part of MEMORAeSoIS to enable collaboration among experts during and after brainstorming sessions. Then, we introduced the PLM systems as part of MEMORAeSoIS and how they fit their resources in the leader system of MEMORAeSoIS. Lastly, we discussed our work with MEMORAeSoIS and how it responds to the main questions of this research.

Chapter 5

Testing MEMORAESoIS application for Web-based Information Systems with open API

5.1 Introduction

In this chapter we present the test results that have been conducted for Web-based Information Systems with open API. This chapter is organized as follows: section 5.2 illustrates the usability test that we conducted with the students at the University of Technology of Compiègne (UTC). Section 5.3, shows the scenario of how the students used the platform within different courses for two semesters. Section 5.4, presents the results of the usability test and the feedback from students. Finally, this chapter is concluded with a summary in section 5.6.

5.2 Usability Test

Before usability testing can be defined, it is necessary to define usability. According to [Barnum and Dragga, 2001], usability means that the people who use the platform can do so quickly and easily to accomplish their own tasks. Also, [Chong, 2017] argues

that a platform's usability is determined by the user's perception of the quality of the platform, based on the user's ease of use, ease of learning, the platforms's intuitiveness for the user, and the user's appreciation of the usefulness of a platform. [Barnum and Dragga, 2001], [Chughtai et al., 2015], and [Chong, 2017] all agree that usability testing has the following characteristics:

- The primary goal is to improve the usability of a product. For each test, there must be specific goals and concerns that you articulate when planning the test.
- The participants must represent real users.
- The participants do real tasks.

The usability tests that we conducted with the students at the University of Technology of Compiègne (UTC) satisfy the previous characteristics. The goals were clear from the beginning. We wanted to test different aspects of MEMORAeSoIS in order to see 1) How easy to use the functionalities of MEMORAeSoIS? 2) Did MEMORAeSoIS facilitate collaboration? 3) What features did they use the most? To get the results from students we used a questionnaire that was categorized into four distinctive sections as following:

- Questions about the functionalities related to the map.
- Questions about the functionalities related to the sharing spaces.
- Questions about functionalities related to the resources.
- Questions related to the MEMORAeSoIS as a platform to support users in their collaborative processes.

The participants in these tests are real users who worked with MEMORAeSoIS to realize real tasks as will be shown in the next section when we present how the students used MEMORAeSoIS, and for what purpose.

5.3 Tests Scenarios

5.3.1 MEMORAeSoIS Test During Spring Semester 2017

This test was conducted in spring semester 2017 for the course NF01. The students used MEMORAeSoIS for one month, from May 2017 to mid June 2017. NF01 is an "Algorithmic and Programming" course that is directed for the first year students at UTC. The users of MEMORAeSoIS in this setting are the students and teachers of this course.

(Fig. 5.1) presents an excerpt from the application ontology formally defining the concepts discussed in the course "Algorithms and Programming". The ontology comes from the work of a former PhD student at UTC [Benayache, 2005]. This ontology defines the semantic content of this course. The defined concepts will be used to index the resources produced by the students enrolled in this course in various ISs.

For the setup of MEMORAeSoIS for this course we include a group of 24 students, each student is provided with an account. This account has access to a map of concepts representing the course. Students then can index, share, comment, and vote on resources related to this course. Also, each student has three sharing spaces: a personal sharing space, a sharing space for the group in which the student belong, and a last sharing space with the instructor of the course.

Students at UTC have access to an online course management and collaboration platform called Moodle. Moodle benefits the students with a learning environment that supports assignment submission, discussion forum, files download, grading, instant messages, online quizzes, and wiki. The aforementioned features help a student to post queries, search for information, read daily posts and comments, and lastly take up an online quiz. In overall view, Moodle provides an encompassing solution for collaboration and course management in a learning ecosystem. What is missing here is a mechanism for sharing and indexing resources in a way that makes it easy for students to find and work with. MEMORAeSoIS provides this mechanism on top of its ability to connect the students with different Information Systems that can help him/her with the learning process. MEMORAeSoIS introduces the idea of a map of shared terminology that is used to index the resources in the learning ecosystem. Furthermore, resources from Moodle can be indexed and shared within MEMORAeSoIS as weblinks as seen in (Fig. 5.2).

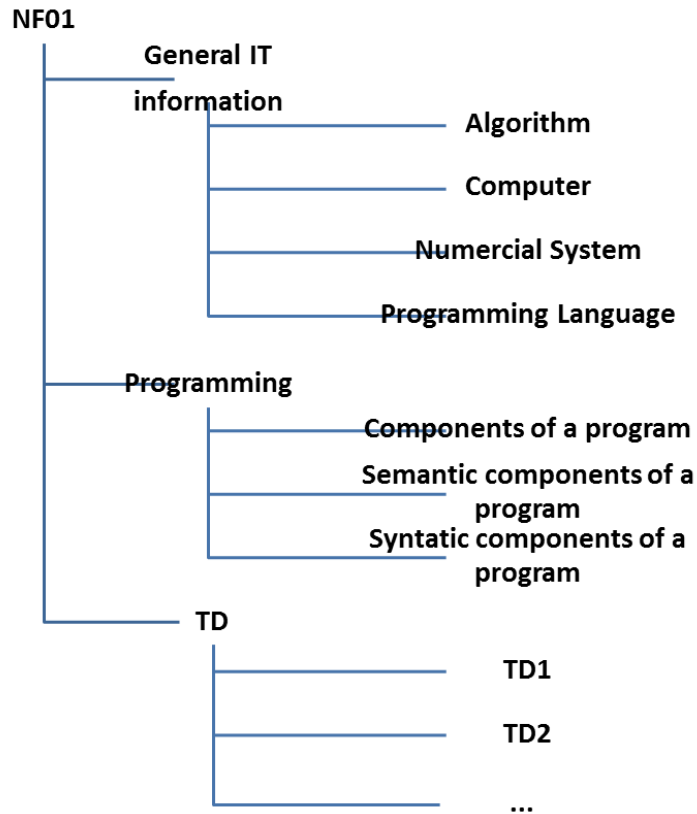


FIGURE 5.1: Part from the application ontology of the course "Algorithms and Programming"

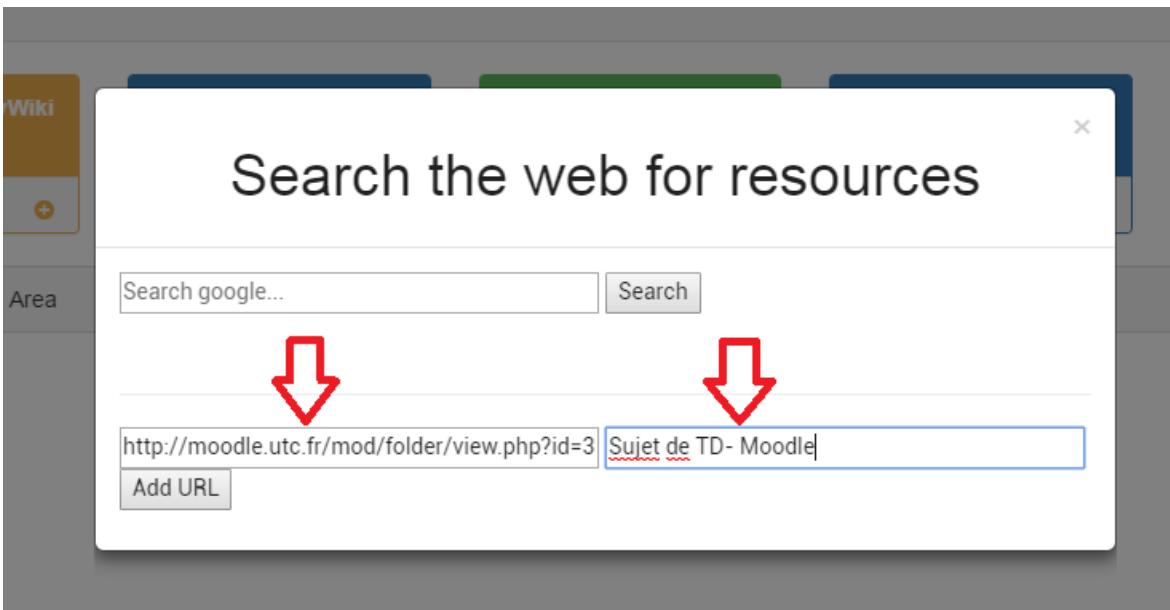


FIGURE 5.2: Add resources from Moodle in MEMORAeSoIS.

After starting to use MEMORAeSoIS, the students contributed their ideas to the map they are using in MEMORAeSoIS. This is also a positive point in favor of MEMORAeSoIS, as the map comes out based on students' needs and requirements. The map represents the notions to be covered in the course and it was originally proposed by [Benayache, 2005]. During the course, the students asked to expand the map with a branch intended for tutorials (TDs) in order to be able to index the resources related to the contents of these TDs. They can thus access the resources by the TD or by the topic treated in the TD; for example: The third TD covers the topic of conditional statements in pascal. When the students want to index resources related to this topic they can index them by the node "TD3" and also the node "conditional statements".

The constituent ISs in MEMORAeSoIS for NF01 are selected based on users' needs (what the students use in their study): TiddlyWiki (wiki page management system), Twitter (social network), Google Search (search engine on the web), Hypothesis (web page annotation system), Google Contacts (contact management system), File Upload (document storage system). Students were required to submit their work in a sharing space with the teacher. They could also share with all of their colleagues in the same group. The students could then vote and show interest of the program and specify in a comment their remarks. While all students shared their programs with the teacher, few shared with their TD peers. The majority, however, consulted those shared and their votes and comments. This helps the most vulnerable to consult programs that run and the authors of the latter to have comments that sometimes propose improvements. Students also added websites to describe and/or complement some aspects of the course.

5.3.2 MEMORAeSoIS Test During Autumn Semester 2017

After the first test of MEMORAeSoIS with the 24 student in NF01 for the spring 2017 semester, we continue for the autumn 2017 semester. We ask the students enrolled in courses IA03 (Technology of Modeling, Capitalizing and Managing Knowledge, 35 students in initial education mode), IA01 (Artificial Intelligence, 117 students in initial education mode), AI02 (Artificial Intelligence: Knowledge representation, 16 students in cooperative education mode), and AI11 (Technology of Modeling, Capitalizing and

TABLE 5.1: Groups of students who used MEMORAeSoIS in their courses.

Groups	Number (Initial Education)	Number (Cooperative Education)	Course	Activities
1 (Students)	117		IA01 (Knowledge representation)	Capitalize course notes. Capitalize any type of additional resources during the course
2 (Students in Work/Study program)		16	AI02 (Knowledge representation)	Capitalize course notes. Capitalize any type of additional resources during the course
3 (Students, sub-part of group 1)	48		IA01 (Knowledge representation)	Capitalize course notes. Capitalize any type of additional resources during the course. Deliver the TD.
4 (Students)	35		IA03 (Tools and methods of KM)	Capitalize course notes. Creation of a map.
5 (Students in Work/Study program)		25	AI11 (Tools and methods of KM)	Capitalize course notes. Creation of a map.

Managing Knowledge, 25 students in cooperative education mode) to use MEMORAeSoIS. The students of IA01 and AI02 were asked to share their notes using MEMORAeSoIS. The students of IA03 and AI11 were asked, beside sharing their notes, to create their own maps that correspond to their group projects. (Table. 5.1) shows the groups of students who used MEMORAeSoIS in their courses.

Similar to NF01, the students will have access to several ISs. Students can index the resources using a map of shared terminology specified to each course, they also can share resources with different sharing spaces created based on the requirements of each course. The sharing spaces are different from the ones used in NF01. For IA01, the user still has a personal sharing space to put resources in it. The sharing space that groups the user with the cours' instructor is omitted. Instead, we can find three sharing spaces. One sharing space contains the members of a group inside the course (The students in one course are divided into groups: D1, D2, D3, etc.). The students can share their work among each other so they can benefit from different ideas and point of views. The next sharing space is common among all the students in the course regardless of their group. This is considered the global sharing space. The third one is the one with the "Notes" of the course. The instructor of the course has access to all these sharing space, except for personal ones, and can evaluate students work in the platform. Other things we add is link to the Google Drive system.

We found that students uses Google Drive to work together on collaborative documents and to backup their files and folders. We think it is a good practice for students to be

able to share their collaborative documents and their uploaded files and folders within MEMORAeSoIS. That will create more complete work environment for the students.

Beside sharing their work within MEMORAeSoIS, the students of IA03 and AI11 are also asked to take projects in which they address a certain subject then provide a model for that subject. This model will eventually turn into a map used in MEMORAeSoIS so the students can use it to capitalize the knowledge concerning the subject of their project. So, students in IA03 and AI11 are not only working with MEMORAeSoIS to share and collaborate their notes, but also they participate in the creation of the map that will present the concepts of their work. They will use this map to capitalize the resources for their projects and test it directly within MEMORAeSoIS. The students will provide OWL files containing the ontology of the map they have created, then these ontologies are uploaded to the knowledge base of the leader system under the proper organization. Then the students can work and interact with the map they have created.

5.4 Test Results

We asked the students at the University of Technology of Compiègne, who used MEMORAeSoIS in their courses, to take a survey to express their experience with the platform. The purpose of any survey is to provide information [Moser and Kalton, 2017]. The goals behind this survey is as follows:

- Get feedback from users of MEMORAeSoIS.
- Evaluate the usability of MEMORAeSoIS in the academic environment.

The survey is organized as a questionnaire for the usability of MEMORAeSoIS. The usability questionnaire consists of 16 questions divided into 4 sections with an extra optional field in each section for comments. In the section about the functionalities related to the map we wanted to get information about the map view and navigation. We focused our questions on the visibility of the map, the navigation of the map, and the coverage of the map's concepts for the subjects of the course. The second section concerning the functionalities related to the sharing spaces has questions about the usefulness of different sharing spaces for the students. The third section about the

TABLE 5.2: Average and standard deviation of the scores for the usability questionnaire.

	Average	Standard Deviation
The visibility of the map is good	7.3	1.9
The navigation of the map is easy and clear	6.4	2
The concepts of the map cover the subjects of the course	7.5	2
The map facilitates organizing the resources	6	2.2
It is necessary to add new concepts to the map	4.7	2.8
Personal sharing spaces facilitates finding my resources	6.4	2.3
The common sharing spaces facilitates finding the resources	6.3	2.2
Having a personal sharing space is useful	5.5	3.2
Having a sharing space for the notes of the course is useful	6.8	2.7
Having a sharing space for the course is useful	6	2.5
It is easy to share resources with my colleagues in MEMORAeSoIS	6.2	2.5
It is easy to index resources with the map	5.4	2.3
The vote and comment functionality is useful	6.6	2.7
MEMORAeSoIS helps in organizing pedagogical resources	6.7	2.4
MEMORAeSoIS helps in sharing pedagogical resources	6.4	2.3
MEMORAeSoIS helps in collaborating on pedagogical resources	5.7	2.5

functionalities related to the resources focuses on the degree of difficulty for sharing and indexing resources, the types of resources the students used the most, and the vote functionality. The last section is dedicated to questions about MEMORAeSoIS as a course support. This section has questions about the degree of satisfaction of users in terms of organizing, sharing, and collaborating on pedagogical resources.

This questionnaire was presented in the form of statements with which students would be more or less in agreement. For each statement, students indicate their degree of agreement with a number included in 0 and 10, a decimal place is allowed, example:

TABLE 5.3: Average and standard deviation of the scores for top 5 users for the usability questionnaire.

	Average	Standard Deviation
The visibility of the map is good	7.9	1
The navigation of the map is easy and clear	6.8	2
The concepts of the map cover the subjects of the course	8.6	1
The map facilitates organizing the resources	7.7	2.2
It is necessary to add new concepts to the map	5.7	2.1
Personal sharing spaces facilitates finding my resources	7.1	0.9
The common sharing spaces facilitates finding the resources	7.7	1.6
Having a personal sharing space is useful	6.6	1.8
Having a sharing space for the notes of the course is useful	8.9	1.1
Having a sharing space for the course is useful	8.7	1.6
It is easy to share resources with my colleagues in MEMORAeSoIS	6.3	1.8
It is easy to index resources with the map	7.6	1.7
The vote and comment functionality is useful	7.7	1.6
MEMORAeSoIS helps in organizing pedagogical resources	7.8	1.9
MEMORAeSoIS helps in sharing pedagogical resources	7.5	1.9
MEMORAeSoIS helps in collaborating on pedagogical resources	6.9	2.1

7.9. 0 means that the student strongly disagree with this statement and 10 means that he/she strongly agree. Time is not limited to answer. However, we asked the students not to stay too long on a question because it is their most spontaneous answer that interests us. There are no good or bad answers. No nominative processing of the answers has been done. The participations to the questionnaires will remain anonymous.

In total, 161 students responded to the MEMORAeSoIS usability questionnaire. The tables presented in this section show the average score and the standard deviation for

TABLE 5.4: Average and standard deviation of the scores for each course.

	IA01 Initial Education		AI02 Cooperative education		IA01 (TD) Initial Education		IA03 Initial Education		AI11 Cooperative education	
	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV	AVG	STDEV
The visibility of the map is good	7.2	1.6	6.8	2.1	7.1	1.8	7.9	1.3	7.3	1.9
The Navigation of the map is easy and clear	5.9	1.9	5.7	2.8	6.8	1.6	6.8	1.8	6.8	2.1
The concepts of the map cover the subjects of the course	7	2.1	7.3	1.9	7.2	2	8.2	0.9	7.6	1.8
The map facilitates organizing the resources	5.2	2.4	5.1	2.9	6.2	1.4	7.1	1.7	6.4	2
It is necessary to add new concepts to the map	4.7	1.6	4.8	1.7	5	2.1	4.3	1.6	4.9	2.3
Personal sharing spaces facilitates finding my resources	6.4	1.9	5.2	2.3	7	1.8	6.8	1.8	6.7	1.7
The common sharing spaces facilitates finding the resources	5.9	2.2	5.7	2.4	6.2	1.8	7.3	1.4	6.4	1.4
Having a personal sharing space is useful	4.8	2.4	5.1	2	5.7	2.9	6.5	1.9	5.2	1.8
Having a sharing space for the notes of the course is useful	6.1	1.7	5.8	1.8	6.4	1.9	7.9	1.1	7.8	1.2
Having a sharing space for the course is useful	5.3	2.1	4.2	2.7	6.2	2.4	7.3	1.6	7.4	2
It is easy to share resources with my colleagues in MEMORAeSoIS	6	1.4	5.7	2.5	6.3	2.3	6.9	1.4	6.1	1.7
It is easy to index resources with the map	5.2	2.2	4.3	2.2	5.8	2.5	6.3	1.9	5.2	2.1
The vote and comment functionality is useful	6.8	1.6	5.9	1.9	7.2	2.8	7.2	1.3	6	1.6
MEMORAeSoIS helps in organizing pedagogical resources	6.9	1.8	5.2	2.6	7.4	1.8	7.6	1.4	6.2	1.9
MEMORAeSoIS helps in sharing pedagogical resources	6.2	1.8	5.4	2.4	6.4	1.7	8.1	1.3	5.8	2.1
MEMORAeSoIS helps in collaborating on pedagogical resources	5.9	2.1	4.7	1.6	6.8	1.8	6.1	1.8	5.2	2.2

students' responses for each statement.

Standard deviation is a number used to tell how measurements for a group are spread out from the average (mean). A low standard deviation means that most of the numbers are very close to the average. A high standard deviation means that the numbers are spread out. In our case, the low standard deviation indicates that students have formed homogeneous opinions about the statements of the questionnaire and there is a high level of agreement among them, while the high standard deviation means that students have different opinion about the statements. We can note from (Table. 5.2) that students' scores tends to be around the neutral average with a standard deviation around 2.4. To get a more accurate response to our survey we choose to select the responses of the users who used MEMORAeSoIS the most. There are 1904 resources that has been shared and indexed in MEMORAeSoIS during the autumn 2017 semester. We take the top 5 students who shared the most and used the platform more than the others. The average and standard deviation for the top 5 users are shown in (Table. 5.3). It is clear that those users have positive and more homogeneous opinions about MEMORAeSoIS.

Also, by taking a look at (Table. 5.4) we are able to see that the students who also worked to create a map of their won have positive views on MEMORAeSoIS. It is clear that these students agree with the statements which describe the good impact of indexing and sharing resources, the ease of use of the map, and the importance of sharing spaces.

From the previous results we can list the following points:

- The map of shared terminology facilitates sharing and indexing resources.
- The map of shared terminology covers the subjects of the courses.
- The most used, and deemed useful, sharing space is the one specific for sharing the notes of the course.
- Votes and comments are useful features to indicate good or bad resources.
- The interface of sharing and indexing resources is not intuitive and poses difficulty to work.
- The least used sharing space is the global sharing space (The one for the whole course).

- Collaboration among students were supported by sharing resources in MEMORAeSoIS.

5.5 Summary

In this chapter we viewed the test of MEMORAeSoIS application for Web-based Information Systems with open API. The test was conducted in an academic environment at the University of Technology of Compiègne (UTC) during two semesters (Spring 2017 and autumn 2017). Students are divided by two education models: The initial education and the cooperative education. Parts of the students not only worked with MEMORAeSoIS to capitalize their resources, but also engaged in the process of creating their own map. Students who used MEMORAeSoIS in their courses took a survey to answer questions related to their experience with the platform. From a total of 215 students 161 students responded to the MEMORAeSoIS usability questionnaire.

The results from the usability test showed that the students, especially those who worked more than others with the platform, have a good impression about the functionalities provided by MEMORAeSoIS. The feedback that we collected will allow us to reflect on current features and advance to provide better experience for users.

Chapter 6

Conclusion, Perspectives and Future Work

6.1 Conclusion

In the context of this thesis, we face the problem of dealing with many Information Systems and the resources produced in them. The problems reside in the time required to traverse between different systems and keep track, organize, and access all the resources obtained from these systems. To scientifically address the challenges stated in the context of this thesis we put the following three questions:

- How to share resources, coming from different ISs, with a community in order to achieve a common goal?
- What is the way to optimize the indexing of shared resources, coming from different ISs, in order to facilitate searching for resources?
- Can we recommend useful resources from different ISs to users?

We found that traditional Digital Ecosystems allows for collaboration and working with heterogeneous resource but on limited scale. They are not customizable, and they do not work well when we want to use new system in the orchestration of a DE. We reached an understanding that we need more flexible approach. This is done by moving forward from a traditional Digital Ecosystem, that does not incorporate change

in an easy way, towards a System of Information Systems that adapt change as one of its key features.

In order to realize the SoIS we adopted the Leader/Follower approach that suggests to have a leader system orchestrating the link with other Information Systems in the digital environment of the SoIS. The first step in our work was to find a Leader system that can help users in: collaboration among peers, heterogeneous resources sharing, accepting resources coming from different ISs and representing the resources for a user in one centralized access point, and providing an added value for users that was not available before when the ISs were working separately. The added value of the SoIS comes from the leader system. For the Role of the leader system we investigated a model of knowledge management and collaboration called MEMORAe-core2. We concluded that this model can be used for building the leader system of the SoIS, and to provide guidance on how to model the SoIS itself. We presented our semantic and architectural model of the SoIS that highlighted our approach for moving forward towards a SoIS. The semantic model of the SoIS presented the different elements and concepts that play main role in realizing a collaborative environment as the SoIS. The architectural model showed how the SoIS can include different ISs (one is the leader system while the others are designated as followers). It also showed that the follower systems can be autonomous as long the leader system can have a way to reference their resources. All the functionalities of the SoIS can then be supplied by the leader system.

Regarding the added values provided by the leader system of the SoIS, we can list them as follows:

- Access heterogeneous resources coming from different ISs in one centralized access point with out the need to query each system individually.
- Share resources using different sharing spaces that contain different members.
- Index resources using a map composed of nodes representing the subjects of interest for collaborators.
- Vote and comment on resources.

- Trace users' activities. This gives perspective about the actions users take concerning two aspects: resources activities (sharing, indexing, voting, and commenting), and navigation activities (what are the nodes, sharing spaces, and resources visited by the user).
- Recommend useful resources to users based on a recommender algorithm.

On the basis of the semantic and architectural model we built the first prototype, MEMORAeSoIS, This prototype helped us to test our SoIS approach with students at UTC. The feedback from the students who used the platform came positive. Other tests are taking place with the students of UTC within different courses. This will help the MEMORAeSoIS to expand and consider new ISs based on students needs.

The strength points for our prototype of MEMORAeSoIS is shown by using it in applications of various domains. From learning ecosystems, brainstorming session, to finally use it as support for PLM systems. This flexibility in application is credited to the architectural model of SoIS that serves as a blueprint to implement all of these different variations of MEMORAeSoIS with simplicity and ease.

6.2 Perspectives and Future Work

To construct a fully functional SoIS prototype based on our SoIS approach is never a complete task. There is always space for improvements. Whether the improvement is in terms of the conceptualization of the model, the technology used for implementation, the features provided by the leader system, the constituent ISs of the SoIS, or even the user experience with the accessibility and interface design. Several perspectives, in our opinion, represent a natural continuation of this work. This section is dedicated for a description of different aspects of such perspectives. Future work can be divided by short-term and long-term. Short-term future work includes:

- It is very important to continue the tests with the students at UTC. The results will gives better understanding about the users' needs and make our approach stand out for the future developments. This will have impact on the ISs that we include in MEMORAeSoIS based on students requirements.

- The design of the link between the recommender system and the leader system can be revised. Here we face two main ideas: One, we can consider the recommender system as an internal feature of the leader system and move its implementation to the leader system (Now it's implemented in Matlab and it's made available to the leader system through node.js server). Two, the recommender system cannot be considered as an external IS constituent in the SoIS. This is because there is no need to index the resources coming from the recommender system. Nonetheless, it can still be considered as an external system providing a service for the leader system (As we currently view it in our architectural model). This will lead to changes in the architectural model, hence, the implementation of the leader system of MEMORAeSoIS as well.
- Our work incorporates a recommender system that recommends resources to users based on their usefulness. Another work has been made in this domain by [Ning, 2016]. This recommender system recommends users to other users based on their competency score. This recommender was realized inside the integrated MEMORAe web client. We think it would be useful to use it in MEMORAeSoIS alongside the resources recommender system.
- Testing the resource recommender system has not been conducted yet because it was being developed during the test with the students. It is a priority to put this task in the short-term list in order to test and validate this important functionality of MEMORAeSoIS.
- Admin panel and super-admin panel needs to be incorporated with MEMORAeSoIS prototype. The admin panel is responsible for creating new user accounts and manage the current users in each organization. The super-admin panel is responsible for creating organizations, adding maps to organizations, and adding sharing spaces to organizations.

The long-term future work includes:

- MEMORAeSoIS has the potential to be a portal for a database that provides "Big Data". As resources' references are accumulated from different ISs they form the core of a Big Data center. New experiences can be acquired from this by focusing on analyzing the heterogeneous resources. For example, a company wants to find a smarter way to do sales forecasts. Usually, the company just looks

at how many products it sold the previous month and how many products it sold a year ago in the month and uses that to make its forecasts. With the resources available in MEMORAeSoIS it can start doing sentiment analysis on Twitter and looking at what people were saying about its products and brands. It also can look at Google Trends to see which products and brands people were searching for the most. So when it makes its sales forecasts, it takes that structured data (how many products it sold last month and a year ago this month) and layers on unstructured data (sentiment analysis from Twitter and Google Trends).

- Filtering the resources that are coming from external IS is an important topic related to SoIS. The SoIS reference resources from different ISs. Some of these systems have long lists of resources that might not all be related to the subjects represented in the map inside MEMORAeSoIS. This problem can be addressed through filtering depending on hashtags or the meta-data of the external resources. Data mining techniques (classification and/or clustering) can be used to predict the resources that should be viewed by the SoIS in the first place. Then the user can index and share from this well-selected sub-list of resources, instead of working with a long list of unwanted resources. Furthermore, the SoIS can suggest relatable nodes to index resources based on their hashtags or meta-data.
- Synchronous communications are important for collaboration. It is worth investigating the possibility of having the systems that enable synchronous communications at the disposal of MEMORAeSoIS users. They can be added as features in the leader system, or they can be considered as external systems and give the users the ability to store, index, and share resources that are coming from these systems.
- Map manipulation can help the users deal with big and complex maps. It is better to have a way to change the view of the map (Maybe 3D view can serve better in some situations), filter the map to focus only on one or two consecutive levels, change the nodes size or color based on the number of resources indexed by the node, etc.
- The platform can benefit from a chatbot that can reply to users' demands about different features of the platform. This will provide more interactive way to work with the resources in MEMORAeSoIS.

Chapter 7

Publications

The work on this thesis resulted in the following publications:

- Mohamed Ali Ben Ameer, Majd Saleh, Marie-Hélène Abel, Elsa Negre. Recommendation of Pedagogical Resources within a Learning Ecosystem. MEDES 2017 The 9th International Conference on Management of Digital EcoSystems, Bangkok, Thailand.
- Majd Saleh, Marie-Helene Abel. System of Information Systems as Support for Learning Ecosystem. In: Huang TC., Lau R., Huang YM., Spaniol M., Yuen CH. (eds) Emerging Technologies for Education. SETE 2017. Lecture Notes in Computer Science, vol 10676, (pp 29–37), Springer, Cham.
- Mohamed Ali Ben Ameer, Majd Saleh, Marie-Hélène Abel, Elsa Negre. Recommandation de ressources pédagogiques au sein d'un système de systèmes d'information. Catherine Roussey. 28es Journées francophones d'Ingénierie des Connaissances IC 2017, Jul 2017, Caen, France. (pp.223-228), Actes IC 2017 28es Journées francophones d'Ingénierie des Connaissances.
- Majd Saleh, Mohamed Ali Ben Ameer, Marie-Hélène Abel. Système de systèmes d'information et écosystème apprenant. Catherine Roussey. 28es Journées francophones d'Ingénierie des Connaissances IC 2017, Jul 2017, Caen, France. (pp.237-240), Actes IC 2017 28es Journées francophones d'Ingénierie des Connaissances.
- Majd Saleh, Marie-Hélène Abel. Modeling and Developing a System of Information Systems for Managing Heterogeneous Resources. SMC 2017 IEEE International Conference On Systems, Man, And Cybernetics, Banff, Canada.

- Majd Saleh, Véronique Misséri, Marie-Hélène Abel. Managing Heterogeneous Information in a System of Information Systems. KMIS 2016 8th International Conference on Knowledge Management and Information Sharing, Nov 2016, Porto, Portugal. (pp. 165-172)
- Majd Saleh, Marie-Hélène Abel, Véronique Misséri, Claude Moulin, David Versailles. Integration of Brainstorming Platform in a System of Information Systems. MEDES 2016 The 8th International ACM Conference on Management of Digital EcoSystems, (pp. 166-173), Nov 2016, Hendaye, France.
- Majd Saleh, and Marie-Hélène Abel. Moving from digital ecosystem to system of information systems. Computer Supported Cooperative Work in Design (CSCWD), 2016 IEEE 20th International Conference on. (pp. 91-96) IEEE, 2016.
- Majd Saleh, Marie-Hélène Abel. Resources Management and Decision Support in a System of Information Systems. The 2nd IEEE International Conference on Industrial Informatics and Computer Systems 2016. Dubai, UAE. (pp. 1-5), 2016.
- Majd Saleh, Marie-Hélène Abel. Information Systems: Towards a System of Information Systems. KMIS 2015 7th International Conference on Knowledge Management and Information Sharing, Nov 2015, Lisbonne, Portugal. Proceedings of the 7th International Joint Conference on Knowledge Discovery, Knowledge Engineering and Knowledge Management - (Volume 3), (pp.193-200), 2015
- Majd Saleh, Marie-Hélène Abel, Alok Mishra. An Architectural Model for System of Information Systems. ISDE15 Sixth International Workshop on Information Systems in Distributed Environment, Oct 2015, Rhodes, Greece. On the Move to Meaningful Internet Systems: OTM 2015 Workshops. Springer International Publishing, 9416, (pp.411-420), 2015
- Majd Saleh, Marie-Hélène Abel, and Véronique Misséri, Investigating the Similarity between Collaboration Systems and Digital Ecosystem, 2015 19th IEEE International Conference on Computer Supported Cooperative Work in Design, (pp. 30-35), 2015

Chapter 8

Bibliography

Bibliography

- [Gar, 2017] (2017). Seize the digital ecosystem opportunity : The 2017 cio agenda (gartner exp cio report), stamford, ct: Gartner inc.
- [Abel, 2015] Abel, M.-H. (2015). Knowledge map-based web platform to facilitate organizational learning return of experiences. *Computers in Human Behavior*, 51:960–966.
- [Ameur et al., 2017a] Ameur, M. A. B., Saleh, M., Abel, M.-H., and Negre, E. (2017a). Recommandation de ressources pédagogiques au sein d’un système de systèmes d’information. In *28es Journées francophones d’Ingénierie des Connaissances IC 2017*, pages 223–228.
- [Ameur et al., 2017b] Ameur, M. A. B., Saleh, M., Abel, M.-H., and Negre, E. (2017b). Recommendation of pedagogical resources within a learning ecosystem. In *The 9th International Conference on Management of Digital EcoSystems*.
- [Atrash, 2015] Atrash, A. (2015). *Modeling a system of expertise capitalization to support organizational learning within small and medium-sized enterprises*. PhD thesis, University OF Technology OF Compiègne.
- [Atrash et al., 2014] Atrash, A., Abel, M.-H., and Moulin, C. (2014). Supporting organizational learning with collaborative annotation. In *International Conference on Knowledge Management and Information Sharing*, pages 237–244.
- [Atrash et al., 2015] Atrash, A., Abel, M.-H., Moulin, C., Darène, N., Huet, F., and Bruaux, S. (2015). Note-taking as a main feature in a social networking platform for small and medium sized enterprises. *Computers in Human Behavior*, 51:705–714.
- [Avison and Fitzgerald, 2003] Avison, D. and Fitzgerald, G. (2003). *Information systems development: methodologies, techniques and tools*. McGraw Hill.

- [Baizid et al., 2017] Baizid, K., Giglio, G., Pierri, F., Trujillo, M. A., Antonelli, G., Caccavale, F., Viguria, A., Chiaverini, S., and Ollero, A. (2017). Behavioral control of unmanned aerial vehicle manipulator systems. *Autonomous Robots*, 41(5):1203–1220.
- [Barnum and Dragga, 2001] Barnum, C. M. and Dragga, S. (2001). *Usability testing and research*. Allyn & Bacon, Inc.
- [Bass, 1969] Bass, F. M. (1969). A new product growth for model consumer durables. *Management science*, 15(5):215–227.
- [Bass and Bass, 2001] Bass, P. and Bass, F. (2001). Diffusion of technology generations: A model of adoption and repeat sales. In *INFORMS Marketing Science Conference presentation*.
- [Bass and Bass, 2004] Bass, P. I. and Bass, F. M. (2004). It waves: Two completed generational diffusion models. *University of Texas, Dallas*.
- [Belhajjame et al., 2017] Belhajjame, K., Cheney, J., Corsar, D., Garijo, D., Soiland-Reyes, S., Zednik, S., and Zhao, J. (2017). Prov-o: The prov ontology. 2013. URL <https://www.w3.org/TR/prov-o>.
- [Benayache, 2005] Benayache, A. (2005). *Construction d'une mémoire organisationnelle de formation et évaluation dans un contexte e-learning: le projet MEMORAE*. PhD thesis, University OF Technology OF Compiègne.
- [Bharadwaj et al., 2013] Bharadwaj, A., El Sawy, O. A., Pavlou, P. A., and Venkatraman, N. V. (2013). Digital business strategy: toward a next generation of insights.
- [Bizoi et al., 2009a] Bizoi, M., Suduc, A., and Filip, F. (2009a). Using collaborative platforms for decision support. In *Proceedings of the 17th International Conference on Control Systems and Computer Science*, pages 349–352. Citeseer.
- [Bizoi et al., 2009b] Bizoi, M., Suduc, A.-M., Gorghiu, G., Gorghiu, L.-M., Rudas, I., Demirafp, M., and Mastorakis, N. (2009b). Rates on collaborative platforms activity in multinational educational projects. In *WSEAS International Conference. Proceedings. Mathematics and Computers in Science and Engineering*, number 9. WSEAS.

- [Bowen and Sahin, 2010] Bowen, R. M. and Sahin, F. (2010). A net-centric xml based system of systems architecture for human tracking. In *System of Systems Engineering (SoSE), 2010 5th International Conference on*, pages 1–6. IEEE.
- [Breitfelder and Messina, 2000] Breitfelder, K. and Messina, D. (2000). Ieee 100: the authoritative dictionary of ieee standards terms. *Standards Information Network IEEE Press. v879*.
- [Breschi and Malerba, 1996] Breschi, S. and Malerba, F. (1996). *Sectoral innovation systems: technological regimes, Schumpeterian dynamics and spatial boundaries*. Centro studi sui processi di internazionalizzazione, Università commerciale'Luigi Bocconi'.
- [Breslin et al., 2009] Breslin, J., Bojars, U., Passant, A., Fernandez, S., and Decker, S. (2009). Sioc: Content exchange and semantic interoperability between social networks.
- [Brickley and Miller, 2010] Brickley, D. and Miller, L. (2010). Foaf vocabulary specification. <http://xmlns.com/foaf/spec/>.
- [Briscoe, 2010] Briscoe, G. (2010). Complex adaptive digital ecosystems. In *Proceedings of the International Conference on Management of Emergent Digital EcoSystems*, pages 39–46. ACM.
- [Brusilovsky and Maybury, 2002] Brusilovsky, P. and Maybury, M. T. (2002). From adaptive hypermedia to the adaptive web. *Communications of the ACM*, 45(5):30–33.
- [Burke, 1999] Burke, R. (1999). Integrating knowledge-based and collaborative-filtering recommender systems. In *Proceedings of the Workshop on AI and Electronic Commerce*, pages 69–72.
- [Burke, 2007] Burke, R. (2007). The adaptive web. chapter hybrid web recommender systems. page 377.
- [Burke et al., 1996] Burke, R. D., Hammond, K. J., and Young, B. C. (1996). Knowledge-based navigation of complex information spaces. In *Proceedings of the national conference on artificial intelligence*, volume 462, page 468.

- [Carlock and Fenton, 2001] Carlock, P. G. and Fenton, R. E. (2001). System of systems (sos) enterprise systems engineering for information-intensive organizations. *Systems engineering*, 4(4):242–261.
- [Carlsson and Stankiewicz, 1991] Carlsson, B. and Stankiewicz, R. (1991). On the nature, function and composition of technological systems. *Journal of evolutionary economics*, 1(2):93–118.
- [Chang and West, 2006] Chang, E. and West, M. (2006). Digital ecosystems a next generation of the collaborative environment. In *iiWAS*, pages 3–24.
- [Chang and Guetl, 2007] Chang, V. and Guetl, C. (2007). E-learning ecosystem (eles)- a holistic approach for the development of more effective learning environment for small-and-medium sized enterprises (smes). In *Digital EcoSystems and Technologies Conference, 2007. DEST'07. Inaugural IEEE-IES*, pages 420–425. IEEE.
- [Chen et al., 2009] Chen, W.-Y., Chu, J.-C., Luan, J., Bai, H., Wang, Y., and Chang, E. Y. (2009). Collaborative filtering for orkut communities: discovery of user latent behavior. In *Proceedings of the 18th international conference on World wide web*, pages 681–690. ACM.
- [Chong, 2017] Chong, F. (2017). Implementing usability testing in introductory technical communication service courses: Results and lessons from a local study. *IEEE Transactions on Professional Communication*.
- [Chughtai et al., 2015] Chughtai, R., Zhang, S., and Craig, S. D. (2015). Usability evaluation of intelligent tutoring system: Its from a usability perspective. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, volume 59, pages 367–371. SAGE Publications Sage CA: Los Angeles, CA.
- [Clark and Jones, 1999] Clark, T. and Jones, R. (1999). Organisational interoperability maturity model for c2. In *Proceedings of the 1999 Command and Control Research and Technology Symposium*.
- [Dahmann, 2015] Dahmann, J. (2015). The state of systems of systems engineering knowledge sources. In *System of Systems Engineering Conference (SoSE), 2015 10th*, pages 475–479. IEEE.
- [Dahmann and Baldwin, 2008] Dahmann, J. S. and Baldwin, K. J. (2008). Understanding the current state of us defense systems of systems and the implications for

- systems engineering. In *Systems Conference, 2008 2nd Annual IEEE*, pages 1–7. IEEE.
- [D’Arcus and Giasson, 2009] D’Arcus, B. and Giasson, F. (2009). Bibliographic ontology specifications. <http://biblontology.com/specification>.
- [Das et al., 2007] Das, A. S., Datar, M., Garg, A., and Rajaram, S. (2007). Google news personalization: scalable online collaborative filtering. In *Proceedings of the 16th international conference on World Wide Web*, pages 271–280. ACM.
- [Davies et al., 2013] Davies, D., Jindal-Snape, D., Collier, C., Digby, R., Hay, P., and Howe, A. (2013). Creative learning environments in education—a systematic literature review. *Thinking Skills and Creativity*, 8:80–91.
- [De Groot et al., 2002] De Groot, R. S., Wilson, M. A., and Boumans, R. M. (2002). A typology for the classification, description and valuation of ecosystem functions, goods and services. *Ecological economics*, 41(3):393–408.
- [Deparis, 2013] Deparis, E. (2013). *Creation of new decisional knowledge for an organization by analysing its social and documentary resources*. Theses, Université de Technologie de Compiègne.
- [Deparis et al., 2014] Deparis, É., Abel, M.-H., Lortal, G., and Mattioli, J. (2014). Information management from social and documentary sources in organizations. *Computers in Human Behavior*, 30:753–759.
- [Dewar and Dutton, 1986] Dewar, R. D. and Dutton, J. E. (1986). The adoption of radical and incremental innovations: An empirical analysis. *Management science*, 32(11):1422–1433.
- [Diffin et al., 2010] Diffin, J., Chirombo, F., and Nangle, D. (2010). Cloud collaboration: using microsoft sharepoint as a tool to enhance access services. *Journal of Library Administration*, 50(5-6):570–580.
- [DiMario, 2006] DiMario, M. J. (2006). System of systems interoperability types and characteristics in joint command and control. In *System of Systems Engineering, 2006 IEEE/SMC International Conference on*, pages 6–pp. IEEE.
- [DiMario et al., 2009] DiMario, M. J., Boardman, J. T., and Sauser, B. J. (2009). System of systems collaborative formation. *IEEE Systems Journal*, 3(3):360–368.

- [Dong and Hussain, 2007] Dong, H. and Hussain, F. K. (2007). Digital ecosystem ontology. In *Industrial Electronics, 2007. ISIE 2007. IEEE International Symposium on*, pages 2944–2947. IEEE.
- [El Sawy and Pereira, 2013] El Sawy, O. A. and Pereira, F. (2013). *Business modelling in the dynamic digital space: An ecosystem approach*. Springer.
- [Fang and DeLaurentis, 2014] Fang, Z. and DeLaurentis, D. (2014). Dynamic planning of system of systems architecture evolution. *Procedia Computer Science*, 28:449–456.
- [Felfernig and Burke, 2008] Felfernig, A. and Burke, R. (2008). Constraint-based recommender systems: technologies and research issues. In *Proceedings of the 10th international conference on Electronic commerce*, page 3. ACM.
- [Felfernig et al., 2007] Felfernig, A., Isak, K., Szabo, K., and Zachar, P. (2007). The vita financial services sales support environment. In *Proceedings of the National Conference on Artificial Intelligence*, volume 22, page 1692. Menlo Park, CA; Cambridge, MA; London; AAAI Press; MIT Press; 1999.
- [Ferronato, 2004] Ferronato, P. (2004). Introduction to the digital business ecosystem project. In *Proceedings of MDA Technical Forum*.
- [Ghazanfar et al., 2012] Ghazanfar, M. A., Prügel-Bennett, A., and Szedmak, S. (2012). Kernel-mapping recommender system algorithms. *Information Sciences, Elsevier*, 208:81–104.
- [Gilly et al., 2011] Gilly, J. P., Talbot, D., and Zuliani, J.-M. (2011). Hub firms and the dynamics of territorial innovation: Case studies of thales and liebherr in toulouse. *European Planning Studies*, 19(12):2009–2024.
- [Goldberg et al., 1992] Goldberg, D., Nichols, D., Oki, B. M., and Terry, D. (1992). Using collaborative filtering to weave an information tapestry. *Communications of the ACM*, 35(12):61–70.
- [Gouider and Abel, 2017] Gouider, S. and Abel, M.-H. (2017). How to take into account informal knowledge in information systems? In *KMIKS 2017-Third International Conference on Knowledge Management, Information and Knowledge Systems*, pages 103–114.

- [Grace et al., 2013] Grace, D. D., Darga, S., Hunsaker, E. N., Elliott, B. R., Viswanathan, R., Schreder, M. J., Lavelle, G. M., Sansbury, D. A., Roche, C., Pandrapagada, R. R., et al. (2013). Knowledge management system. US Patent 8,589,196.
- [Group et al., 1998] Group, C. A. W. et al. (1998). Levels of information systems interoperability (lisi). *United States, Department of Defense*.
- [Gruber, 1995] Gruber, T. R. (1995). Toward principles for the design of ontologies used for knowledge sharing? volume 43, pages 907–928. Elsevier.
- [Guy et al., 2009] Guy, I., Ronen, I., and Wilcox, E. (2009). Do you know?: recommending people to invite into your social network. In *Proceedings of the 14th international conference on Intelligent user interfaces*, pages 77–86. ACM.
- [Guy et al., 2010] Guy, I., Zwerdling, N., Ronen, I., Carmel, D., and Uziel, E. (2010). Social media recommendation based on people and tags. In *Proceedings of the 33rd international ACM SIGIR conference on Research and development in information retrieval*, pages 194–201. ACM.
- [Haag et al., 1998] Haag, S., Cummings, M., and Dawkins, J. (1998). *Management information systems for the information age*. McGraw-Hill.
- [Heijst et al., 1997] Heijst, G. v., Schreiber, A., and Wielinga, B. (1997). Roles are not classes: a reply to nicola guarino. volume 46, pages 311 – 318.
- [Huber, 1991] Huber, G. P. (1991). Organizational learning: The contributing processes and the literatures. volume 2, pages 88–115. INFORMS.
- [Iansiti and Levien, 2004] Iansiti, M. and Levien, R. (2004). Strategy as ecology. *Harvard business review*, 82(3):68–81.
- [Jamshidi, 2011] Jamshidi, M. (2011). *System of systems engineering: innovations for the twenty-first century*, volume 58. John Wiley & Sons.
- [Jannach et al., 2010] Jannach, D., Zanker, M., Felfernig, A., and Friedrich, G. (2010). *Recommender systems: an introduction*. Cambridge University Press.
- [Karakas, 2009] Karakas, F. (2009). Welcome to world 2.0: the new digital ecosystem. *Journal of Business Strategy*, 30(4):23–30.

- [Karcnias, 2008] Karcnias, N. (2008). Structure evolving systems and control in integrated design. *Annual reviews in Control*, 32(2):161–182.
- [Karcnias and Hessami, 2010] Karcnias, N. and Hessami, A. (2010). Complexity and the notion of system of systems: Part (ii): defining the notion of system of systems. In *World Automation Congress (WAC), 2010*, pages 1–7. IEEE.
- [Laurillard, 2006] Laurillard, D. (2006). E-learning in higher education. *Changing higher education: The development of learning and teaching*, pages 71–84.
- [Lindeman, 1942] Lindeman, R. L. (1942). The trophic-dynamic aspect of ecology. *Ecology*, 23(4):399–417.
- [Loch and Huberman, 1999] Loch, C. H. and Huberman, B. A. (1999). A punctuated-equilibrium model of technology diffusion. *Management Science*, 45(2):160–177.
- [Lomas et al., 2008] Lomas, C., Burke, M., and Page, C. L. (2008). Collaboration tools. *Educause learning initiative*, 2.
- [Lozano et al., 2008] Lozano, R., Spong, M. W., Guerrero, J. A., and Chopra, N. (2008). Controllability and observability of leader-based multi-agent systems. In *Decision and Control, 2008. CDC 2008. 47th IEEE Conference on*, pages 3713–3718. IEEE.
- [Luzeaux et al., 2013] Luzeaux, D. et al. (2013). *Systems of systems*. John Wiley & Sons.
- [Lytras and Sicilia, 2005] Lytras, M. D. and Sicilia, A. (2005). The semantic learning organization. volume 12, pages 402–410. Emerald Group Publishing Limited.
- [Madni and Sievers, 2014] Madni, A. M. and Sievers, M. (2014). System of systems integration: Key considerations and challenges. *Systems Engineering*, 17(3):330–347.
- [Maier, 1996] Maier, M. W. (1996). Architecting principles for systems-of-systems. In *INCOSE International Symposium*, volume 6, pages 565–573. Wiley Online Library.
- [Manthorpe, 1996] Manthorpe, W. H. (1996). The emerging joint system of systems: A systems engineering challenge and opportunity for apl. *Johns Hopkins APL Technical Digest*, 17(3):305.

- [Manvi and Shyam, 2014] Manvi, S. S. and Shyam, G. K. (2014). Resource management for infrastructure as a service (iaas) in cloud computing: A survey. *Journal of Network and Computer Applications*, 41:424–440.
- [McAfee, 2009] McAfee, A. (2009). *Enterprise 2.0: New collaborative tools for your organization's toughest challenges*. Harvard Business Press.
- [McMeekin et al., 2009] McMeekin, D. A., Hadzic, M., and Chang, E. (2009). Sequence diagrams: an aid for digital ecosystem developers. In *Digital Ecosystems and Technologies, 2009. DEST'09. 3rd IEEE International Conference on*, pages 674–678. IEEE.
- [Mikroyannidis, 2007] Mikroyannidis, A. (2007). Toward a social semantic web. *Computer*, 40(11):113–115.
- [Mirzadeh et al., 2005] Mirzadeh, N., Ricci, F., and Bansal, M. (2005). Feature selection methods for conversational recommender systems. In *e-Technology, e-Commerce and e-Service, 2005. EEE'05. Proceedings. The 2005 IEEE International Conference on*, pages 772–777. IEEE.
- [Mishra et al., 2010] Mishra, A. K., Hellerstein, J. L., Cirne, W., and Das, C. R. (2010). Towards characterizing cloud backend workloads: insights from google compute clusters. *ACM SIGMETRICS Performance Evaluation Review*, 37(4):34–41.
- [Moore, 1996] Moore, J. (1996). *The death of competition: Leadership and strategy in the age of business ecosystems harper collins*. New York, NY.
- [Morris et al., 2004] Morris, E., Levine, L., Meyers, C., Place, P., and Plakosh, D. (2004). System of systems interoperability (sosi). Technical report, Carnegie-mellon univ pittsburgh pa software engineering inst.
- [Moser and Kalton, 2017] Moser, C. A. and Kalton, G. (2017). *Survey methods in social investigation*. Routledge.
- [Negre, 2015] Negre, E. (2015). *Information and Recommender Systems*. John Wiley & Sons.
- [Ning, 2016] Ning, W. (2016). *Towards a Competency Recommender System from Collaborative Traces*. PhD thesis, University OF Technology OF Compiègne.

- [Noguera et al., 2017] Noguera, J., Ayeni, F. E., Okuboyejo, S., and Adusumilli, S. (2017). Towards a web based adaptive and intelligent tutoring system. *International Journal of Computing and Informatics (IJCANDI)*, 1(1).
- [Oh et al., 2015] Oh, K.-K., Park, M.-C., and Ahn, H.-S. (2015). A survey of multi-agent formation control. *Automatica*, 53:424–440.
- [Paik and Choi, 2005] Paik, Y. and Choi, D. Y. (2005). The shortcomings of a standardized global knowledge management system: The case study of accenture. *The Academy of Management Executive*, 19(2):81–84.
- [Pazzani and Billsus, 2007] Pazzani, M. J. and Billsus, D. (2007). Content-based recommendation systems. In *The adaptive web*, pages 325–341. Springer.
- [Peng et al., 2014] Peng, X., Babar, M. A., and Ebert, C. (2014). Collaborative software development platforms for crowdsourcing. *IEEE software*, 31(2):30–36.
- [Pickett and Cadenasso, 2002] Pickett, S. T. and Cadenasso, M. L. (2002). The ecosystem as a multidimensional concept: meaning, model, and metaphor. *Ecosystems*, 5(1):1–10.
- [Rama and Bishop, 2006] Rama, J. and Bishop, J. (2006). A survey and comparison of cscw groupware applications. In *Proceedings of the 2006 annual research conference of the South African institute of computer scientists and information technologists on IT research in developing countries*, pages 198–205. South African Institute for Computer Scientists and Information Technologists.
- [Rechtin and Maier, 2000] Rechtin, E. and Maier, M. W. (2000). *The art of systems architecting*. CRC Press.
- [Renato and M., 2014] Renato, I. and M., J. (2014). vcard ontology - for describing people and organizations. <http://www.w3.org/TR/vcard-rdf/>.
- [Reynolds, 2014] Reynolds, D. (2014). The organization ontology. <http://www.w3.org/TR/vocab-org/>.
- [Ricci and Nguyen, 2007] Ricci, F. and Nguyen, Q. N. (2007). Acquiring and revising preferences in a critique-based mobile recommender system. *IEEE Intelligent systems*, 22(3).

- [Ricci et al., 2011] Ricci, F., Rokach, L., and Shapira, B. (2011). Introduction to recommender systems handbook. In *Recommender systems handbook*, pages 1–35. Springer.
- [Robert et al., 2013] Robert, S., Paolo, C., and Herbert, V. (2013). Open annotation data model. <http://www.openannotation.org/spec/core/>.
- [Sage and Cuppan, 2001] Sage, A. P. and Cuppan, C. D. (2001). On the systems engineering and management of systems of systems and federations of systems. *Information, Knowledge, Systems Management*, 2(4):325–345.
- [Saleh and Abel, 2015] Saleh, M. and Abel, M.-H. (2015). Information systems: Towards a system of information systems. In *KMIS 2015 7th International Conference on Knowledge Management and Information Sharing*, pages 193–200.
- [Saleh and Abel, 2016a] Saleh, M. and Abel, M.-H. (2016a). Moving from digital ecosystem to system of information systems. In *Computer Supported Cooperative Work in Design (CSCWD), 2016 IEEE 20th International Conference on*, pages 91–96. IEEE.
- [Saleh and Abel, 2016b] Saleh, M. and Abel, M.-H. (2016b). Resources management and decision support in a system of information systems. In *Industrial Informatics and Computer Systems (CIICS), 2016 International Conference on*, pages 1–5. IEEE.
- [Saleh and Abel, 2017a] Saleh, M. and Abel, M.-H. (2017a). Modeling and developing a system of information systems for managing heterogeneous resources. pages 2672–2677.
- [Saleh and Abel, 2017b] Saleh, M. and Abel, M.-H. (2017b). System of information systems as support for learning ecosystem. In *International Symposium on Emerging Technologies for Education*, pages 29–37. Springer.
- [Saleh et al., 2015a] Saleh, M., Abel, M.-H., and Mishra, A. (2015a). An architectural model for system of information systems. In *OTM Confederated International Conferences” On the Move to Meaningful Internet Systems”*, pages 411–420. Springer.
- [Saleh et al., 2015b] Saleh, M., Abel, M.-H., and Misséri, V. (2015b). Investigating the similarity between collaboration systems and digital ecosystems. In *Computer*

- Supported Cooperative Work in Design (CSCWD)*, 2015 IEEE 19th International Conference on, pages 30–35. IEEE.
- [Saleh et al., 2016a] Saleh, M., Abel, M.-H., Misséri, V., Moulin, C., and Versailles, D. (2016a). Integration of brainstorming platform in a system of information systems. In *Proceedings of the 8th International Conference on Management of Digital EcoSystems*, pages 166–173. ACM.
- [Saleh et al., 2017] Saleh, M., Ameer, M. A. B., and Abel, M.-H. (2017). Système de systèmes d’information et écosystème apprenant. In *28es Journées francophones d’Ingénierie des Connaissances IC 2017*, pages 237–240.
- [Saleh et al., 2016b] Saleh, M., Misséri, V., and Abel, M.-H. (2016b). Managing heterogeneous information in a system of information systems. In *KMIS 2016 8th International Conference on Knowledge Management and Information Sharing*.
- [Schein et al., 2002] Schein, A. I., Popescul, A., Ungar, L. H., and Pennock, D. M. (2002). Methods and metrics for cold-start recommendations. In *Proceedings of the 25th annual international ACM SIGIR conference on Research and development in information retrieval*, pages 253–260. ACM.
- [SEBoK, 2017] SEBoK (2017). Systems of systems (sos) — guide to the systems engineering body of knowledge (sebok), version 1.8.
- [Sigurbjörnsson and Van Zwol, 2008] Sigurbjörnsson, B. and Van Zwol, R. (2008). Flickr tag recommendation based on collective knowledge. In *Proceedings of the 17th international conference on World Wide Web*, pages 327–336. ACM.
- [Simpson and Dagli, 2008] Simpson, J. J. and Dagli, C. H. (2008). System of systems: Power and paradox. In *System of Systems Engineering, 2008. SoSE’08. IEEE International Conference on*, pages 1–5. IEEE.
- [Smyth et al., 2004] Smyth, B., McGinty, L., Reilly, J., and McCarthy, K. (2004). Compound critiques for conversational recommender systems. In *Web Intelligence, 2004. WI 2004. Proceedings. IEEE/WIC/ACM International Conference on*, pages 145–151. IEEE.
- [Tansley, 1935] Tansley, A. G. (1935). The use and abuse of vegetational concepts and terms. *Ecology*, 16(3):284–307.

- [Terveen and Hill, 2001] Terveen, L. and Hill, W. (2001). Beyond recommender systems: Helping people help each other. *HCI in the New Millennium*, 1(2001):487–509.
- [Terzi et al., 2010] Terzi, S., Bouras, A., Dutta, D., Garetti, M., and Kiritsis, D. (2010). Product lifecycle management—from its history to its new role. *International Journal of Product Lifecycle Management*, 4(4):360–389.
- [Thompson et al., 2004] Thompson, C. A., Goker, M. H., and Langley, P. (2004). A personalized system for conversational recommendations. *Journal of Artificial Intelligence Research*, 21:393–428.
- [Trewin, 2000] Trewin, S. (2000). Knowledge-based recommender systems. *Encyclopedia of library and information science*, 69(Supplement 32):180.
- [Wang et al., 2015] Wang, N., Abel, M.-H., Barthes, J.-P., and Negre, E. (2015). Mining user competency from semantic trace. In *Computer Supported Cooperative Work in Design (CSCWD), 2015 IEEE 19th International Conference on*, pages 48–53. IEEE.
- [Wang et al., 2016] Wang, N., Abel, M.-H., Barthès, J.-P., and Negre, E. (2016). An answerer recommender system exploiting collaboration in cqa services. In *Computer Supported Cooperative Work in Design (CSCWD), 2016 IEEE 20th International Conference on*, pages 198–203. IEEE.
- [Wang et al., 2009] Wang, W., Tolk, A., and Wang, W. (2009). The levels of conceptual interoperability model: applying systems engineering principles to m&s. In *Proceedings of the 2009 Spring Simulation Multiconference*, page 168. Society for Computer Simulation International.
- [Wasson, 2015] Wasson, C. S. (2015). *System engineering analysis, design, and development: Concepts, principles, and practices*. John Wiley & Sons.
- [Weill and Woerner, 2015] Weill, P. and Woerner, S. L. (2015). Thriving in an increasingly digital ecosystem. *MIT Sloan Management Review*, 56(4):27.
- [Wilkinson et al., 2016] Wilkinson, M. D., Dumontier, M., Aalbersberg, I. J., Appleton, G., Axton, M., Baak, A., Blomberg, N., Boiten, J.-W., da Silva Santos, L. B., Bourne, P. E., et al. (2016). The fair guiding principles for scientific data management and stewardship. *Scientific data*, 3:160018.

- [Xu et al., 2014] Xu, B., Da Xu, L., Cai, H., Xie, C., Hu, J., and Bu, F. (2014). Ubiquitous data accessing method in iot-based information system for emergency medical services. *IEEE Transactions on Industrial Informatics*, 10(2):1578–1586.

Chapter 9

Appendices

Appendix A

The Complete MEMORAE-core2 OWL Ontology

```
<?xml version="1.0"?>
<!DOCTYPE rdf:RDF [
<!ENTITY sioc "http://rdfs.org/sioc/ns#" >
<!ENTITY terms "http://purl.org/dc/terms/" >
<!ENTITY wot "http://xmlns.com/wot/0.1/" >
<!ENTITY foaf "http://xmlns.com/foaf/0.1/" >
<!ENTITY owl "http://www.w3.org/2002/07/owl#" >
<!ENTITY bibo "http://purl.org/ontology/bibo/" >
<!ENTITY dc "http://purl.org/dc/elements/1.1/" >
<!ENTITY xsd "http://www.w3.org/2001/XMLSchema#" >
<!ENTITY event "http://purl.org/NET/c4dm/event.owl#" >
<!ENTITY skos "http://www.w3.org/2004/02/skos/core#" >
<!ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema#" >
<!ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns#" >
<!ENTITY ns "http://www.w3.org/2003/06/sw-vocab-status/ns#" >
]>
<rdf:RDF xmlns="http://www.hds.utc.fr/mc2/tbox#"
xml:base="http://www.hds.utc.fr/mc2/tbox"
xmlns:ns="http://www.w3.org/2003/06/sw-vocab-status/ns#"
xmlns:owl="http://www.w3.org/2002/07/owl#"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
xmlns:skos="http://www.w3.org/2004/02/skos/core#"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:terms="http://purl.org/dc/terms/"
xmlns:bibo="http://purl.org/ontology/bibo/"
xmlns:event="http://purl.org/NET/c4dm/event.owl#"
xmlns:wot="http://xmlns.com/wot/0.1/"
xmlns:foaf="http://xmlns.com/foaf/0.1/"
xmlns:dc="http://purl.org/dc/elements/1.1/"
xmlns:sioc="http://rdfs.org/sioc/ns#">
<owl:Ontology rdf:about="http://www.hds.utc.fr/mc2/tbox">
<dc:modified rdf:datatype="&xsd;dateTime">2013-02-22T21:40:51+01:00</dc:modified>
<dc:title xml:lang="en">SIOC Core Ontology Namespace</dc:title>
<dc:description>The Friend of a Friend (FOAF) RDF vocabulary, described using W3C RDF Schema and the Web Ontology
Language.</dc:description>
<owl:versionInfo>Revision: 1.35</owl:versionInfo>
<owl:versionInfo>0.9.20130208</owl:versionInfo>
<owl:versionInfo>http://purl.org/ontology/bibo/1.3/</owl:versionInfo>
<dc:title>Friend of a Friend (FOAF) vocabulary</dc:title>
<dc:title>The Bibliographic Ontology</dc:title>
<dc:title xml:lang="en">Open Annotation Data Model</dc:title>
<owl:imports rdf:resource="http://purl.org/ontology/bibo/" />
<rdfs:seeAlso rdf:resource="http://rdfs.org/sioc/spec" />
<owl:imports rdf:resource="http://rdfs.org/sioc/ns#" />
<rdfs:seeAlso rdf:resource="http://www.openannotation.org/spec/core/20130208/index.html" />
<owl:imports rdf:resource="http://www.openannotation.org/spec/core/20130208/oa.owl" />
<owl:imports rdf:resource="http://xmlns.com/foaf/0.1/" />
</owl:Ontology>
<!--
////////////////////////////////////
//
// Annotation properties
//
////////////////////////////////////
-->
<!-- http://purl.org/dc/terms/creator -->
<owl:AnnotationProperty rdf:about="&terms;creator" />
<!-- http://purl.org/dc/terms/date -->
<owl:AnnotationProperty rdf:about="&terms;date" />
```

```
<!-- http://purl.org/dc/terms/description -->
<owl:AnnotationProperty rdf:about="&terms;description"/>
<!-- http://purl.org/dc/terms/identifier -->
<owl:AnnotationProperty rdf:about="&terms;identifier"/>
<!-- http://purl.org/dc/terms/title -->
<owl:AnnotationProperty rdf:about="&terms;title"/>
<!-- http://www.w3.org/2002/07/owl#deprecated -->
<owl:AnnotationProperty rdf:about="&owl;deprecated"/>
<!-- http://www.w3.org/2003/06/sw-vocab-status/ns#term_status -->
<owl:AnnotationProperty rdf:about="&ns;term_status"/>
<!-- http://www.w3.org/2004/02/skos/core#changeNote -->
<owl:AnnotationProperty rdf:about="&skos;changeNote"/>
<!-- http://www.w3.org/2004/02/skos/core#editorialNote -->
<owl:AnnotationProperty rdf:about="&skos;editorialNote"/>
<!-- http://www.w3.org/2004/02/skos/core#example -->
<owl:AnnotationProperty rdf:about="&skos;example"/>
<!-- http://www.w3.org/2004/02/skos/core#historyNote -->
<owl:AnnotationProperty rdf:about="&skos;historyNote"/>
<!-- http://www.w3.org/2004/02/skos/core#note -->
<owl:AnnotationProperty rdf:about="&skos;note"/>
<!-- http://www.w3.org/2004/02/skos/core#scopeNote -->
<owl:AnnotationProperty rdf:about="&skos;scopeNote"/>
<!-- http://xmlns.com/foaf/0.1/membershipClass -->
<owl:AnnotationProperty rdf:about="&foaf;membershipClass">
<rdfs:label>membershipClass</rdfs:label>
<rdfs:comment>Indicates the class of individuals that are a member of a Group</rdfs:comment>
<ns:term_status>unstable</ns:term_status>
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1"/>
</owl:AnnotationProperty>
<!-- http://xmlns.com/foaf/0.1/name -->
<owl:AnnotationProperty rdf:about="&foaf;name">
<rdfs:subPropertyOf rdf:resource="&rdfs;label"/>
<rdfs:domain rdf:resource="&owl;Thing"/>
</owl:AnnotationProperty>
<!-- http://xmlns.com/wot/0.1/assurance -->
<owl:AnnotationProperty rdf:about="&wot;assurance"/>
<!-- http://xmlns.com/wot/0.1/src_assurance -->
<owl:AnnotationProperty rdf:about="&wot;src_assurance"/>
<!--
////////////////////////////////////
//
// Object Properties
//
////////////////////////////////////
-->
<!-- http://rdfs.org/sioc/ns#account_of -->
<owl:ObjectProperty rdf:about="&sioc;account_of">
<rdfs:label xml:lang="en">account of</rdfs:label>
<rdfs:comment xml:lang="en">Refers to the foaf:Agent or foaf:Person who owns this sioc:UserAccount.</rdfs:comment>
<rdfs:domain rdf:resource="&sioc;UserAccount"/>
<rdfs:range rdf:resource="&foaf;Agent"/>
<owl:inverseOf rdf:resource="&foaf;account"/>
</owl:ObjectProperty>
<!-- http://rdfs.org/sioc/ns#has_administrator -->
<owl:ObjectProperty rdf:about="&sioc;has_administrator">
<rdfs:label xml:lang="en">has administrator</rdfs:label>
<rdfs:comment xml:lang="en">A UserAccount that is an administrator of this Site.</rdfs:comment>
<rdfs:domain rdf:resource="&sioc;Site"/>
<rdfs:range rdf:resource="&sioc;UserAccount"/>
</owl:ObjectProperty>
```

```
<!-- http://rdfs.org/sioc/ns#has_creator -->
<owl:ObjectProperty rdf:about="&sioc;has_creator">
<rdfs:label xml:lang="en">has creator</rdfs:label>
<rdfs:comment xml:lang="en">This is the UserAccount that made this resource.</rdfs:comment>
<rdfs:range rdf:resource="&sioc;UserAccount"/>
</owl:ObjectProperty>
<!-- http://rdfs.org/sioc/ns#has_member -->
<owl:ObjectProperty rdf:about="&sioc;has_member">
<rdfs:label xml:lang="en">has member</rdfs:label>
<rdfs:comment xml:lang="en">A UserAccount that is a member of this Usergroup.</rdfs:comment>
<rdfs:range rdf:resource="&sioc;UserAccount"/>
<rdfs:domain rdf:resource="&sioc;Usergroup"/>
</owl:ObjectProperty>
<!-- http://rdfs.org/sioc/ns#has_usergroup -->
<owl:ObjectProperty rdf:about="&sioc;has_usergroup">
<rdfs:label xml:lang="en">has usergroup</rdfs:label>
<rdfs:comment xml:lang="en">Points to a Usergroup that has certain access to this Space.</rdfs:comment>
<rdfs:domain rdf:resource="&sioc;Space"/>
<rdfs:range rdf:resource="&sioc;Usergroup"/>
</owl:ObjectProperty>
<!-- http://rdfs.org/sioc/ns#member_of -->
<owl:ObjectProperty rdf:about="&sioc;member_of">
<rdfs:label xml:lang="en">member of</rdfs:label>
<rdfs:comment xml:lang="en">A Usergroup that this UserAccount is a member of.</rdfs:comment>
<rdfs:domain rdf:resource="&sioc;UserAccount"/>
<rdfs:range rdf:resource="&sioc;Usergroup"/>
<owl:inverseOf rdf:resource="&sioc;has_member"/>
</owl:ObjectProperty>
<!-- http://rdfs.org/sioc/ns#space_of -->
<owl:ObjectProperty rdf:about="&sioc;space_of">
<rdfs:label xml:lang="en">space of</rdfs:label>
<rdfs:comment xml:lang="en">A resource which belongs to this data Space.</rdfs:comment>
<rdfs:domain rdf:resource="&sioc;Space"/>
</owl:ObjectProperty>
<!-- http://rdfs.org/sioc/ns#usergroup_of -->
<owl:ObjectProperty rdf:about="&sioc;usergroup_of">
<rdfs:label xml:lang="en">usergroup of</rdfs:label>
<rdfs:comment xml:lang="en">A Space that the Usergroup has access to.</rdfs:comment>
<rdfs:range rdf:resource="&sioc;Space"/>
<rdfs:domain rdf:resource="&sioc;Usergroup"/>
<owl:inverseOf rdf:resource="&sioc;has_usergroup"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#about_class -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#about_class">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2/tbox#IndexKey"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#bought_by -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#bought_by">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2/tbox#BuySellResource"/>
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#BuyActivity"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#ConsumedResource"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#ManufacturingResource"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#composed_of -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#composed_of">
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#Activity"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#Activity"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#consumed_by -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#consumed_by">
```

```
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#ManufacturingActivity"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#ConsumedResource"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#containes -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#containes">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2/tbox#CompositeResource"/>
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2/tbox#Resource"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#hasBody -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#hasBody">
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2/tbox#Resource"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2oa/tbox#Annotation"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#hasTarget -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#hasTarget">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2oa/tbox#Annotation"/>
<rdfs:range rdf:resource="&owl;Thing"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#index -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#index">
<rdfs:label>index</rdfs:label>
<dc:description xml:lang="fr">Permet de définir un lien entre une certaine clé d'indexation et une ressource</dc:description>
<owl:inverseOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#indexed_by"/>
<rdfs:range>
<owl:Restriction>
<owl:onProperty rdf:resource="http://www.hds.utc.fr/mc2/tbox#index"/>
<owl:someValuesFrom rdf:resource="http://www.hds.utc.fr/mc2/tbox#Resource"/>
</owl:Restriction>
</rdfs:range>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#indexed_by -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#indexed_by">
<rdfs:label xml:lang="en">indexed by</rdfs:label>
<rdfs:label xml:lang="fr">indexé par</rdfs:label>
<dc:description xml:lang="fr">Permet de lier une ressource à une certaine clé d'indexation</dc:description>
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2/tbox#IndexKey"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2/tbox#Resource"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#involved_agent -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#involved_agent">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2event/tbox#Event"/>
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2foaf/tbox#Agent"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#involved_by -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#involved_by">
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#ManufacturingActivity"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#ManufacturingResource"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#is_visible_for -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#is_visible_for">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2/tbox#IndexKey"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#produced_by -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#produced_by">
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#ManufacturingActivity"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#ProducedResource"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#require -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#require">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#Activity"/>
```

```

</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#share -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#share">
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2/tbox#Resource"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2soic/tbox#User"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#sold_by -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#sold_by">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2/tbox#BuySellResource"/>
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#SellActivity"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#BuySellProduct"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#ProducedResource"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2role/tbox#has_authority -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2role/tbox#has_authority">
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2role/tbox#Authority"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2role/tbox#Role"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2role/tbox#has_goal -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2role/tbox#has_goal">
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2roal/tbox#Goal"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2role/tbox#Role"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2role/tbox#has_resource -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2role/tbox#has_resource">
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2/tbox#Resource"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2event/tbox#Event"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2role/tbox#Role"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2role/tbox#requires_skill -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2role/tbox#requires_skill">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2role/tbox#Role"/>
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2role/tbox#Skill"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/mc2vcard/tbox#workAdr -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/mc2vcard/tbox#workAdr">
<rdfs:range rdf:resource="http://www.hds.utc.fr/mc2vcard/tbox#Address"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/mc2vcard/tbox#Vcard"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/tour/tbox#composed_OfEvents -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/tour/tbox#composed_OfEvents">
<rdfs:range rdf:resource="http://www.hds.utc.fr/event/tbox#Event"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/tour/tbox#Tour"/>
</owl:ObjectProperty>
<!-- http://www.hds.utc.fr/vcard/tbox#workAdr -->
<owl:ObjectProperty rdf:about="http://www.hds.utc.fr/vcard/tbox#workAdr">
<rdfs:range rdf:resource="http://www.hds.utc.fr/vcard/tbox#Address"/>
<rdfs:domain rdf:resource="http://www.hds.utc.fr/vcard/tbox#Vcard"/>
</owl:ObjectProperty>
<!-- http://www.w3.org/ns/oa#hasBody -->
<owl:ObjectProperty rdf:about="http://www.w3.org/ns/oa#hasBody">
<rdfs:label xml:lang="en">hasBody</rdfs:label>
<rdfs:comment xml:lang="en">The relationship between oa:Annotation and body. The body is somehow &quot;about&quot; the
oa:hasTarget of the annotation.
The Body may be of any media type, and contain any type of content. The Body SHOULD be identified by HTTP URIs unless they are
embedded
within the Annotation.
Embedded bodies SHOULD be instances of cnt:ContentAsText and embed their content with cnt:chars. They SHOULD declare their media
type
with dc:format, and MAY indicate their language using dc:language and a RFC-3066 language tag.

```

There is no OA class provided for "Body" as a body might be a target of a different annotation. However, there SHOULD be 1 or more content-based classes associated with the body resources of an Annotation, and the dctypes: vocabulary is recommended for this purpose, for instance dctypes:Text to declare textual content.

```
</rdfs:comment>
<rdfs:isDefinedBy rdf:resource="http://www.w3.org/ns/oa#" />
<rdfs:domain rdf:resource="http://www.w3.org/ns/oa#Annotation" />
</owl:ObjectProperty>
<!-- http://www.w3.org/ns/oa#hasTarget -->
<owl:ObjectProperty rdf:about="http://www.w3.org/ns/oa#hasTarget">
<rdfs:label xml:lang="en">hasTarget</rdfs:label>
<rdfs:comment xml:lang="en">The relationship between oa:Annotation and target. The target resource is what the oa:hasBody is somewhat &quot;about&quot;;
```

The target may be of any media type, and contain any type of content. The target SHOULD be identified by HTTP URIs unless they are embedded within the Annotation.

Embedded targets SHOULD be instances of cnt:ContentAsText and embed their content with cnt:chars. They SHOULD declare their media type with dc:format, and MAY indicate their language using dc:language and a RFC-3066 language tag.

There is no OA class provided for "Target" as a target might be a body in a different annotation. However, there SHOULD be 1 or more content-based classes associated with the target resources of an Annotation, and the dctypes: vocabulary is recommended for this purpose, for instance dctypes:Text to declare textual content.</rdfs:comment>

```
<rdfs:isDefinedBy rdf:resource="http://www.w3.org/ns/oa#" />
<rdfs:domain rdf:resource="http://www.w3.org/ns/oa#Annotation" />
</owl:ObjectProperty>
<!-- http://xmlns.com/foaf/0.1/account -->
<owl:ObjectProperty rdf:about="&foaf;account">
<rdfs:label>account</rdfs:label>
<ns:term_status>testing</ns:term_status>
<rdfs:comment>Indicates an account held by this agent.</rdfs:comment>
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1/" />
<rdfs:range rdf:resource="&foaf;OnlineAccount" />
</owl:ObjectProperty>
```

```
<!--
////////////////////////////////////
//
// Data properties
//
////////////////////////////////////
-->
```

```
<!-- http://rdfs.org/sioc/ns#first_name -->
<owl:DatatypeProperty rdf:about="&sioc;first_name">
<rdfs:label xml:lang="en">first name</rdfs:label>
<owl:deprecated rdf:datatype="&xsd:boolean">true</owl:deprecated>
<rdfs:comment xml:lang="en">First (real) name of this User. Synonyms include given name or christian name.</rdfs:comment>
<owl:versionInfo>This property is deprecated. Use foaf:name or foaf:firstName from the FOAF vocabulary instead.</owl:versionInfo>
<rdfs:domain rdf:resource="&sioc;UserAccount" />
<rdfs:range rdf:resource="&rdfs;Literal" />
</owl:DatatypeProperty>
<!-- http://rdfs.org/sioc/ns#last_name -->
<owl:DatatypeProperty rdf:about="&sioc;last_name">
<rdfs:label xml:lang="en">last name</rdfs:label>
<owl:deprecated rdf:datatype="&xsd:boolean">true</owl:deprecated>
<owl:versionInfo>This property is deprecated. Use foaf:name or foaf:surname from the FOAF vocabulary instead.</owl:versionInfo>
<rdfs:comment xml:lang="en">Last (real) name of this user. Synonyms include surname or family name.</rdfs:comment>
<rdfs:domain rdf:resource="&sioc;UserAccount" />
<rdfs:range rdf:resource="&rdfs;Literal" />
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/contact/tbox#contactfirstName -->
```

```
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/contact/tbox#contactfirstName">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/contact/tbox#Contact"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/contact/tbox#genre -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/contact/tbox#genre">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/contact/tbox#Contact"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/event/event/tbox#has_StartTime -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/event/event/tbox#has_StartTime"/>
<!-- http://www.hds.utc.fr/event/tbox#has_Address -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/event/tbox#has_Address">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/event/tbox#Event"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/event/tbox#has_Duration -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/event/tbox#has_Duration">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/event/tbox#Event"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/event/tbox#has_EndDate -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/event/tbox#has_EndDate">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/event/tbox#Event"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/event/tbox#has_Place -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/event/tbox#has_Place">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/event/tbox#Event"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/event/tbox#has_StartDate -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/event/tbox#has_StartDate"/>
<!-- http://www.hds.utc.fr/mc2/tbox#has_Email -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#has_Email">
<rdfs:range rdf:resource="&rdfs:Literal"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#has_Login -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#has_Login">
<rdfs:range rdf:resource="&rdfs:Literal"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#has_Office -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#has_Office">
<rdfs:range rdf:resource="&rdfs:Literal"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#has_Page -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#has_Page">
<rdfs:range rdf:resource="&rdfs:Literal"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#has_Password -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#has_Password">
<rdfs:range rdf:resource="&rdfs:Literal"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#has_PhoneNumber -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#has_PhoneNumber">
<rdfs:range rdf:resource="&rdfs:Literal"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#has_subjet -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#has_subjet">
<rdfs:range rdf:resource="&rdfs:Literal"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/mc2/tbox#postal-code -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/mc2/tbox#postal-code">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/vcard/tbox#Address"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/tour/tbox#has_Duration -->
```



```
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/tour/tbox#has_Duration">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/tour/tbox#Tour"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/tour/tbox#has_EndDate -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/tour/tbox#has_EndDate">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/tour/tbox#Tour"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/tour/tbox#has_StartDate -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/tour/tbox#has_StartDate">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/tour/tbox#Tour"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/tour/tbox#has_StartTime -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/tour/tbox#has_StartTime">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/tour/tbox#Tour"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/vcard/tbox#city -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/vcard/tbox#city">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/vcard/tbox#Address"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/vcard/tbox#street-address -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/vcard/tbox#street-address">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/vcard/tbox#Address"/>
</owl:DatatypeProperty>
<!-- http://www.hds.utc.fr/vcard/tbox#workTel -->
<owl:DatatypeProperty rdf:about="http://www.hds.utc.fr/vcard/tbox#workTel">
<rdfs:domain rdf:resource="http://www.hds.utc.fr/vcard/tbox#Vcard"/>
</owl:DatatypeProperty>
<!-- http://xmlns.com/foaf/0.1/familyName -->
<owl:DatatypeProperty rdf:about="&foaf;familyName">
<rdfs:label>familyName</rdfs:label>
<rdfs:comment>The family name of some person.</rdfs:comment>
<ns:term_status>testing</ns:term_status>
<rdfs:range rdf:resource="&rdfs;Literal"/>
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1/" />
</owl:DatatypeProperty>
<!-- http://xmlns.com/foaf/0.1/family_name -->
<owl:DatatypeProperty rdf:about="&foaf;family_name">
<rdfs:label>family_name</rdfs:label>
<rdfs:comment>The family name of some person.</rdfs:comment>
<ns:term_status>archaic</ns:term_status>
<skos:scopeNote xml:lang="en">This is the property we choose to use to describe the family name of a person related to a bibliographic resource.</skos:scopeNote>
<rdfs:range rdf:resource="&rdfs;Literal"/>
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1/" />
</owl:DatatypeProperty>
<!-- http://xmlns.com/foaf/0.1/firstName -->
<owl:DatatypeProperty rdf:about="&foaf;firstName">
<rdfs:label>firstName</rdfs:label>
<ns:term_status>testing</ns:term_status>
<rdfs:comment>The first name of a person.</rdfs:comment>
<rdfs:range rdf:resource="&rdfs;Literal"/>
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1/" />
</owl:DatatypeProperty>
<!-- http://xmlns.com/foaf/0.1/gender -->
<owl:DatatypeProperty rdf:about="&foaf;gender">
<rdf:type rdf:resource="&owl;FunctionalProperty"/>
<rdfs:label>gender</rdfs:label>
<ns:term_status>testing</ns:term_status>
<rdfs:comment>The gender of this Agent (typically but not necessarily &apos;male&apos; or &apos;female&apos;).</rdfs:comment>
<rdfs:range rdf:resource="&rdfs;Literal"/>
```

```
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1/" />
</owl:DatatypeProperty>
<!-- http://xmlns.com/foaf/0.1/givenName -->
<owl:DatatypeProperty rdf:about="&foaf;givenName">
<rdfs:label>Given name</rdfs:label>
<rdfs:comment>The given name of some person.</rdfs:comment>
<ns:term_status>testing</ns:term_status>
<rdfs:range rdf:resource="&rdfs;Literal" />
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1/" />
</owl:DatatypeProperty>
<!-- http://xmlns.com/foaf/0.1/givename -->
<owl:DatatypeProperty rdf:about="&foaf;givename">
<rdfs:label>Given name</rdfs:label>
<ns:term_status>archaic</ns:term_status>
<rdfs:comment>The given name of some person.</rdfs:comment>
<skos:scopeNote xml:lang="en">This is the property we choose to describe the given name of a Person related to a bibliographic resource.
This is the first name of a person.</skos:scopeNote>
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1/" />
</owl:DatatypeProperty>
<!-- http://xmlns.com/foaf/0.1/lastName -->
<owl:DatatypeProperty rdf:about="&foaf;lastName">
<rdfs:label>lastName</rdfs:label>
<rdfs:comment>The last name of a person.</rdfs:comment>
<ns:term_status>testing</ns:term_status>
<rdfs:range rdf:resource="&rdfs;Literal" />
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1/" />
</owl:DatatypeProperty>
<!--
////////////////////////////////////
//
// Classes
//
////////////////////////////////////
-->
<!-- http://purl.org/dc/terms/Agent -->
<owl:Class rdf:about="&terms;Agent">
<owl:equivalentClass rdf:resource="&foaf;Agent" />
<skos:editorialNote xml:lang="en">BIBO assert that a dcterms:Agent is an equivalent class to foaf:Agent.
This means that all the individuals belonging to the foaf:Agent class
also belongs to the dcterms:Agent class. This way, dcterms:contributor
can be used on foaf:Person, foaf:Organization, foaf:Agent and foaf:Group.
Even if this link is not done in neither the FOAF nor the DCTERMS ontologies this is a wide spread fact that is asserted by
BIBO.</skos:editorialNote>
</owl:Class>
<!-- http://purl.org/ontology/bibo/Document -->
<owl:Class rdf:about="&bibo;Document">
<rdfs:label xml:lang="en">Document</rdfs:label>
<owl:equivalentClass rdf:resource="&foaf;Document" />
<rdfs:isDefinedBy rdf:datatype="&xsd:anyURI">http://purl.org/ontology/bibo/</rdfs:isDefinedBy>
<rdfs:comment xml:lang="en">A document (noun) is a bounded physical representation of body of information designed with the capacity
(and usually intent) to communicate. A document may manifest symbolic, diagrammatic or sensory-representational
information.</rdfs:comment>
<ns:term_status>stable</ns:term_status>
</owl:Class>
<!-- http://purl.org/ontology/bibo/Note -->
<owl:Class rdf:about="&bibo;Note">
<rdfs:label xml:lang="en">Note</rdfs:label>
<rdfs:subClassOf rdf:resource="&bibo;Document" />
<rdfs:isDefinedBy rdf:datatype="&xsd:anyURI">http://purl.org/ontology/bibo/</rdfs:isDefinedBy>
<ns:term_status>stable</ns:term_status>
```

```

<rdfs:comment xml:lang="en">Notes or annotations about a resource.</rdfs:comment>
</owl:Class>
<!-- http://rdfs.org/sioc/ns#Site -->
<owl:Class rdf:about="&sioc;Site">
<rdfs:label xml:lang="en">Site</rdfs:label>
<rdfs:subClassOf rdf:resource="&sioc;Space"/>
<rdfs:comment xml:lang="en">A Site can be the location of an online community or set of communities, with UserAccounts and Usergroups
creating Items in a set of Containers. It can be thought of as a web-accessible data Space.</rdfs:comment>
</owl:Class>
<!-- http://rdfs.org/sioc/ns#Space -->
<owl:Class rdf:about="&sioc;Space">
<rdfs:label xml:lang="en">Space</rdfs:label>
<owl:disjointWith rdf:resource="&sioc;User"/>
<owl:disjointWith rdf:resource="&sioc;UserAccount"/>
<owl:disjointWith rdf:resource="&sioc;Usergroup"/>
<rdfs:comment xml:lang="en">A Space is a place where data resides, e.g. on a website, desktop, fileshare, etc.</rdfs:comment>
</owl:Class>
<!-- http://rdfs.org/sioc/ns#User -->
<owl:Class rdf:about="&sioc;User">
<rdfs:label xml:lang="en">User</rdfs:label>
<owl:equivalentClass rdf:resource="&sioc;UserAccount"/>
<rdfs:subClassOf rdf:resource="&foaf;OnlineAccount"/>
<owl:disjointWith rdf:resource="&sioc;Usergroup"/>
<owl:deprecated rdf:datatype="&xsd:boolean">true</owl:deprecated>
<owl:versionInfo>This class is deprecated. Use sioc:UserAccount from the SIOC ontology instead.</owl:versionInfo>
<rdfs:comment xml:lang="en">UserAccount is now preferred. This is a deprecated class for a User in an online community
site.</rdfs:comment>
</owl:Class>
<!-- http://rdfs.org/sioc/ns#UserAccount -->
<owl:Class rdf:about="&sioc;UserAccount">
<rdfs:label xml:lang="en">User Account</rdfs:label>
<rdfs:subClassOf rdf:resource="&foaf;OnlineAccount"/>
<owl:disjointWith rdf:resource="&sioc;Usergroup"/>
<rdfs:comment xml:lang="en">A user account in an online community site.</rdfs:comment>
</owl:Class>
<!-- http://rdfs.org/sioc/ns#Usergroup -->
<owl:Class rdf:about="&sioc;Usergroup">
<rdfs:label xml:lang="en">Usergroup</rdfs:label>
<rdfs:comment xml:lang="en">A set of UserAccounts whose owners have a common purpose or interest. Can be used for access control
purposes.</rdfs:comment>
</owl:Class>
<!-- http://www.hds.utc.fr/activity/tbox#Activity -->
<owl:Class rdf:about="http://www.hds.utc.fr/activity/tbox#Activity"/>
<!-- http://www.hds.utc.fr/activity/tbox#BuyActivity -->
<owl:Class rdf:about="http://www.hds.utc.fr/activity/tbox#BuyActivity">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/activity/tbox#Activity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/activity/tbox#ManufacturingActivity -->
<owl:Class rdf:about="http://www.hds.utc.fr/activity/tbox#ManufacturingActivity">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/activity/tbox#Activity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/activity/tbox#SellActivity -->
<owl:Class rdf:about="http://www.hds.utc.fr/activity/tbox#SellActivity">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/activity/tbox#Activity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/agenda/tbox#Agenda -->
<owl:Class rdf:about="http://www.hds.utc.fr/agenda/tbox#Agenda"/>
<!-- http://www.hds.utc.fr/contact/tbox#Contact -->
<owl:Class rdf:about="http://www.hds.utc.fr/contact/tbox#Contact"/>
<!-- http://www.hds.utc.fr/contact/tbox#GroupContact -->

```

```

<owl:Class rdf:about="http://www.hds.utc.fr/contact/tbox#GroupContact">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/contact/tbox#Contact"/>
</owl:Class>
<!-- http://www.hds.utc.fr/contact/tbox#OrganizationContact -->
<owl:Class rdf:about="http://www.hds.utc.fr/contact/tbox#OrganizationContact">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/contact/tbox#Contact"/>
</owl:Class>
<!-- http://www.hds.utc.fr/contact/tbox#PersonContact -->
<owl:Class rdf:about="http://www.hds.utc.fr/contact/tbox#PersonContact">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/contact/tbox#Contact"/>
</owl:Class>
<!-- http://www.hds.utc.fr/enterprise/tbox#Corporation -->
<owl:Class rdf:about="http://www.hds.utc.fr/enterprise/tbox#Corporation">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/enterprise/tbox#Legal-Entity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/enterprise/tbox#Legal-Entity -->
<owl:Class rdf:about="http://www.hds.utc.fr/enterprise/tbox#Legal-Entity"/>
<!-- http://www.hds.utc.fr/enterprise/tbox#Partnership -->
<owl:Class rdf:about="http://www.hds.utc.fr/enterprise/tbox#Partnership">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/enterprise/tbox#Legal-Entity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/enterprise/tbox#Person -->
<owl:Class rdf:about="http://www.hds.utc.fr/enterprise/tbox#Person">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/enterprise/tbox#Legal-Entity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/event/tbox#Event -->
<owl:Class rdf:about="http://www.hds.utc.fr/event/tbox#Event"/>
<!-- http://www.hds.utc.fr/mc2/tbox#BuySellResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#BuySellResource">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#SimpleResource"/>
<dc:description xml:lang="en">Products which are bought by the enterprise to be sold for profit purpose.</dc:description>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2/tbox#Chat -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#Chat">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#CompositeResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2/tbox#CompositeResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#CompositeResource">
<rdfs:label xml:lang="en">Composite Resource</rdfs:label>
<rdfs:label xml:lang="fr">Ressource composée</rdfs:label>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#Resource"/>
<dc:description xml:lang="fr">Une ressource composée peut être vide ou composée d'une ou plusieurs ressources.</dc:description>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2/tbox#Forum -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#Forum">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#CompositeResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2/tbox#IndexKey -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#IndexKey"/>
<!-- http://www.hds.utc.fr/mc2/tbox#NoteCluster -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#NoteCluster">
<rdfs:label xml:lang="en">Note Cluster</rdfs:label>
<rdfs:label xml:lang="fr">Groupement de notes</rdfs:label>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#CompositeResource"/>
<dc:description xml:lang="en">A Note Cluster could be empty or composed by one or more other Note Clusters and/or Notes</dc:description>
<dc:description xml:lang="fr">Un cluster de notes peut être vide ou composé d'un ou plusieurs clusters de notes et/ou d'une ou plusieurs notes</dc:description>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2/tbox#Resource -->

```

```
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#Resource">
<rdfs:label xml:lang="en">Resource</rdfs:label>
<rdfs:label xml:lang="fr">Ressource</rdfs:label>
<dc:description xml:lang="fr">Une ressource est un vecteur d'informations</dc:description>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2/tbox#SimpleResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#SimpleResource">
<rdfs:label xml:lang="en">Simple Resource</rdfs:label>
<rdfs:label xml:lang="fr">Ressource unitaire</rdfs:label>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#Resource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2/tbox#Space -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#Space">
<rdfs:subClassOf rdf:resource="sioc:Space"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2/tbox#WikiPage -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#WikiPage">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2bibo/tbox#Document"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2/tbox#wiki -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2/tbox#wiki">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#CompositeResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2activity/tbox#Activity -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2activity/tbox#Activity">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/activity/tbox#Activity"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#SimpleResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2activity/tbox#BuyActivity -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2activity/tbox#BuyActivity">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/activity/tbox#BuyActivity"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#Activity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2activity/tbox#ManufacturingActivity -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2activity/tbox#ManufacturingActivity">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/activity/tbox#ManufacturingActivity"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#Activity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2activity/tbox#SellActivity -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2activity/tbox#SellActivity">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/activity/tbox#SellActivity"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2activity/tbox#Activity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2agenda/tbox#Agenda -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2agenda/tbox#Agenda">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/agenda/tbox#Agenda"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#CompositeResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2bibo/tbox#Document -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2bibo/tbox#Document">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#SimpleResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2bibo/tbox#Note -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2bibo/tbox#Note">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2bibo/tbox#Document"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2contact/tbox#Contact -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2contact/tbox#Contact">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/contact/tbox#Contact"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2foaf/tbox#Agent"/>
```

```
</owl:Class>
<!-- http://www.hds.utc.fr/mc2contact/tbox#GroupContact -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2contact/tbox#GroupContact">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/contact/tbox#GroupContact"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2contact/tbox#Contact"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2contact/tbox#OrganizationContact -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2contact/tbox#OrganizationContact">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/contact/tbox#OrganizationContact"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2contact/tbox#Contact"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2contact/tbox#PersonContact -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2contact/tbox#PersonContact">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/contact/tbox#PersonContact"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2contact/tbox#Contact"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2enterprise/tbox#ClientEnterprise -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2enterprise/tbox#ClientEnterprise">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2enterprise/tbox#Enterprise"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2enterprise/tbox#Enterprise -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2enterprise/tbox#Enterprise">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2enterprise/tbox#PrivateLegalEntity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2enterprise/tbox#LegalEntity -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2enterprise/tbox#LegalEntity">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/enterprise/tbox#Legal-Entity"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2foaf/tbox#Agent"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2enterprise/tbox#PrivateLegalEntity -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2enterprise/tbox#PrivateLegalEntity">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2enterprise/tbox#LegalEntity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2enterprise/tbox#ProspetEnterprise -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2enterprise/tbox#ProspetEnterprise">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2enterprise/tbox#Enterprise"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2enterprise/tbox#PublicLegalEntity -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2enterprise/tbox#PublicLegalEntity">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2enterprise/tbox#LegalEntity"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2event/tbox#Event -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2event/tbox#Event">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/event/tbox#Event"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#SimpleResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2foaf/tbox#Agent -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2foaf/tbox#Agent">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#SimpleResource"/>
<rdfs:subClassOf rdf:resource="&foaf;Agent"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2foaf/tbox#Group -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2foaf/tbox#Group">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2foaf/tbox#Agent"/>
<rdfs:subClassOf rdf:resource="&foaf;Group"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2foaf/tbox#Organization -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2foaf/tbox#Organization">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2foaf/tbox#Agent"/>
<rdfs:subClassOf rdf:resource="&foaf;Organization"/>
```

```
</owl:Class>
<!-- http://www.hds.utc.fr/mc2foaf/tbox#Person -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2foaf/tbox#Person">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2foaf/tbox#Agent"/>
<rdfs:subClassOf rdf:resource="&foaf;Person"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2mr/tbox#BuySellProduct -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2mr/tbox#BuySellProduct">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#MaterialResource"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#BuySellProduct"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2mr/tbox#ConsumedResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2mr/tbox#ConsumedResource">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#MaterialResource"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#ConsumedResource"/>
<dc:description>Resources that can be consumed during activities.</dc:description>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2mr/tbox#Machine -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2mr/tbox#Machine">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#ManufacturingResource"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#Machine"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2mr/tbox#ManufacturingResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2mr/tbox#ManufacturingResource">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#MaterialResource"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#ManufacturingResource"/>
<dc:description>Resources that play a certain role during activities.</dc:description>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2mr/tbox#MaterialResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2mr/tbox#MaterialResource">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#SimpleResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2mr/tbox#ProducedResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2mr/tbox#ProducedResource">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#MaterialResource"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#ProducedResource"/>
<dc:description xml:lang="en">The products produced in the enterprise itself to be sold</dc:description>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2mr/tbox#RawMaterial -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2mr/tbox#RawMaterial">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#ConsumedResource"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#RawMaterial"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2mr/tbox#SpecificProduct -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2mr/tbox#SpecificProduct">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#ProducedResource"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#SpecificProduct"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2mr/tbox#StandardProduct -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2mr/tbox#StandardProduct">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2mr/tbox#ProducedResource"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#StandardProduct"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2oa/tbox#Annotation -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2oa/tbox#Annotation">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#SimpleResource"/>
<rdfs:subClassOf rdf:resource="http://www.w3.org/ns/oa#Annotation"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2roal/tbox#Goal -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2roal/tbox#Goal">
```

```
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/role/tbox#Goal"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2role/tbox#Authority -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2role/tbox#Authority">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/role/tbox#Authority"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2role/tbox#Commercial -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2role/tbox#Commercial">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2role/tbox#Role"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2role/tbox#Designer -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2role/tbox#Designer">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2role/tbox#Role"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2role/tbox#Role -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2role/tbox#Role">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/role/tbox#Role"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2role/tbox#Skill -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2role/tbox#Skill">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/rolr/tbox#Skill"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2soic/tbox#FreeGroup -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2soic/tbox#FreeGroup">
<rdfs:subClassOf rdf:resource="&sioc;Usergroup"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2soic/tbox#InstitutionalGroup -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2soic/tbox#InstitutionalGroup">
<rdfs:subClassOf rdf:resource="&sioc;Usergroup"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2soic/tbox#PersonalGroup -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2soic/tbox#PersonalGroup">
<rdfs:subClassOf rdf:resource="&sioc;Usergroup"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2soic/tbox#User -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2soic/tbox#User">
<rdfs:subClassOf rdf:resource="&sioc;UserAccount"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2tour/tbox#Tour -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2tour/tbox#Tour">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mc2/tbox#CompositeResource"/>
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/tour/tbox#Tour"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2vcard/tbox#Address -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2vcard/tbox#Address">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/vcard/tbox#Address"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mc2vcard/tbox#Vcard -->
<owl:Class rdf:about="http://www.hds.utc.fr/mc2vcard/tbox#Vcard">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/vcard/tbox#Vcard"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mr/tbox#BuySellProduct -->
<owl:Class rdf:about="http://www.hds.utc.fr/mr/tbox#BuySellProduct">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#MaterialResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mr/tbox#ConsumedResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mr/tbox#ConsumedResource">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#MaterialResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mr/tbox#Machine -->
```



```

<owl:Class rdf:about="http://www.hds.utc.fr/mr/tbox#Machine">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#ManufacturingResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mr/tbox#ManufacturingResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mr/tbox#ManufacturingResource">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#MaterialResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mr/tbox#MaterialResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mr/tbox#MaterialResource"/>
<!-- http://www.hds.utc.fr/mr/tbox#ProducedResource -->
<owl:Class rdf:about="http://www.hds.utc.fr/mr/tbox#ProducedResource">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#MaterialResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mr/tbox#RawMaterial -->
<owl:Class rdf:about="http://www.hds.utc.fr/mr/tbox#RawMaterial">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#ConsumedResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mr/tbox#SpecificProduct -->
<owl:Class rdf:about="http://www.hds.utc.fr/mr/tbox#SpecificProduct">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#ProducedResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/mr/tbox#StandardProduct -->
<owl:Class rdf:about="http://www.hds.utc.fr/mr/tbox#StandardProduct">
<rdfs:subClassOf rdf:resource="http://www.hds.utc.fr/mr/tbox#ProducedResource"/>
</owl:Class>
<!-- http://www.hds.utc.fr/role/tbox#Authority -->
<owl:Class rdf:about="http://www.hds.utc.fr/role/tbox#Authority"/>
<!-- http://www.hds.utc.fr/role/tbox#Goal -->
<owl:Class rdf:about="http://www.hds.utc.fr/role/tbox#Goal"/>
<!-- http://www.hds.utc.fr/role/tbox#Role -->
<owl:Class rdf:about="http://www.hds.utc.fr/role/tbox#Role"/>
<!-- http://www.hds.utc.fr/rolr/tbox#Skill -->
<owl:Class rdf:about="http://www.hds.utc.fr/rolr/tbox#Skill"/>
<!-- http://www.hds.utc.fr/tour/tbox#Tour -->
<owl:Class rdf:about="http://www.hds.utc.fr/tour/tbox#Tour"/>
<!-- http://www.hds.utc.fr/vcard/tbox#Address -->
<owl:Class rdf:about="http://www.hds.utc.fr/vcard/tbox#Address"/>
<!-- http://www.hds.utc.fr/vcard/tbox#Vcard -->
<owl:Class rdf:about="http://www.hds.utc.fr/vcard/tbox#Vcard"/>
<!-- http://www.w3.org/2002/07/owl#Thing -->
<owl:Class rdf:about="&owl;Thing">
<rdfs:label>Thing</rdfs:label>
</owl:Class>
<!-- http://www.w3.org/ns/oa#Annotation -->
<owl:Class rdf:about="http://www.w3.org/ns/oa#Annotation">
<rdfs:label xml:lang="en">Annotation</rdfs:label>
<rdfs:comment xml:lang="en">Typically an Annotation has a single Body (oa:hasBody), which is the comment or other descriptive resource,
and a single Target (oa:hasTarget) that the Body is somehow &quot;about&quot;. The Body provides the information which is annotating the
Target.
This &quot;aboutness&quot; may be further clarified or extended to notions such as classifying or identifying with
oa:motivatedBy.</rdfs:comment>
<rdfs:isDefinedBy rdf:resource="http://www.w3.org/ns/oa#"/>
</owl:Class>
<!-- http://www.w3.org/ns/oa#SemanticTag -->
<owl:Class rdf:about="http://www.w3.org/ns/oa#SemanticTag">
<rdfs:label xml:lang="en">SemanticTag</rdfs:label>
<rdfs:subClassOf rdf:resource="http://www.w3.org/ns/oa#Tag"/>
<rdfs:comment xml:lang="en">A class assigned to the Body when it is a semantic tagging resource; a URI that identifies a concept, rather
than an embedded string, frequently a term from a controlled vocabulary.

```

It is NOT RECOMMENDED to use the URI of a document as a Semantic Tag, as it might also be used as a regular Body in other Annotations which would inherit the oa:SemanticTag class assignment. Instead it is more appropriate to create a new URI and link it to the document, using the foaf:page predicate.</rdfs:comment>

```
<rdfs:isDefinedBy rdf:resource="http://www.w3.org/ns/oa#" />
</owl:Class>
```

```
<!-- http://www.w3.org/ns/oa#SpecificResource -->
```

```
<owl:Class rdf:about="http://www.w3.org/ns/oa#SpecificResource">
```

```
<rdfs:label xml:lang="en">SpecificResource</rdfs:label>
```

```
<rdfs:comment xml:lang="en">A resource identifies part of another Source resource, a particular representation of a resource, a resource with styling hints for renders, or any combination of these.
```

The Specific Resource takes the role of oa:hasBody or oa:hasTarget in an oa:Annotation instead of the Source resource.

There MUST be exactly 1 oa:hasSource relationship associated with a Specific Resource.

There MUST be exactly 0 or 1 oa:hasSelector relationship associated with a Specific Resource.

There MAY be 0 or 1 oa:hasState relationship for each Specific Resource.

If the Specific Resource has an HTTP URI, then the exact segment of the Source resource that it identifies, and only the segment, MUST be returned when the URI is dereferenced. For example, if the segment of interest is a region of an image and the Specific Resource has an HTTP URI, then dereferencing it MUST return the selected region of the image as it was at the time when the annotation was created. Typically this would be a burden to support, and thus the Specific Resource SHOULD be identified by a globally unique URI, such as a UUID URN. If it is not considered important to allow other Annotations or systems to refer to the Specific Resource, then a blank node MAY be used instead.</rdfs:comment>

```
<rdfs:isDefinedBy rdf:resource="http://www.w3.org/ns/oa#" />
```

```
</owl:Class>
```

```
<!-- http://www.w3.org/ns/oa#Tag -->
```

```
<owl:Class rdf:about="http://www.w3.org/ns/oa#Tag">
```

```
<rdfs:label xml:lang="en">Tag</rdfs:label>
```

```
<rdfs:comment xml:lang="en">A class assigned to the Body when it is a tag, such as a embedded text string with cnt:chars.
```

Tags are typically keywords or labels, and used for organization, description or discovery of the resource being tagged. In the Semantic Web, URIs

are used instead of strings to avoid the issue of polysemy where one word has multiple meanings, such usage MUST be indicated using the subclass oa:SemanticTag.

Annotations that tag resources, either with text or semantic tags, SHOULD also have the oa:tagging motivation to make the reason for the Annotation more clear to applications, and MAY have other motivations as well.</rdfs:comment>

```
<rdfs:isDefinedBy rdf:resource="http://www.w3.org/ns/oa#" />
```

```
</owl:Class>
```

```
<!-- http://xmlns.com/foaf/0.1/Agent -->
```

```
<owl:Class rdf:about="&foaf;Agent">
```

```
<skos:scopeNote xml:lang="en">Used to describe any &quot;agent&quot; related to bibliographic items. Such agents can be persons, organizations or groups of any kind.</skos:scopeNote>
```

```
</owl:Class>
```

```
<!-- http://xmlns.com/foaf/0.1/Document -->
```

```
<owl:Class rdf:about="&foaf;Document">
```

```
<rdfs:label>Document</rdfs:label>
```

```
<owl:disjointWith rdf:resource="&foaf;Organization" />
```

```
<rdfs:comment>A document.</rdfs:comment>
```

```
<ns:term_status>testing</ns:term_status>
```

```
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1/" />
```

```
</owl:Class>
```

```
<!-- http://xmlns.com/foaf/0.1/Group -->
```

```
<owl:Class rdf:about="&foaf;Group">
```

```
<rdfs:subClassOf rdf:resource="&foaf;Agent" />
```

```
</owl:Class>
```

```
<!-- http://xmlns.com/foaf/0.1/OnlineAccount -->
```

```
<owl:Class rdf:about="&foaf;OnlineAccount">
```

```
<rdfs:label>Online Account</rdfs:label>
```

```
<rdfs:subClassOf rdf:resource="&owl;Thing" />
```

```
<rdfs:comment>An online account.</rdfs:comment>
```

```
<ns:term_status>testing</ns:term_status>
```

```
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1/" />
```

```
</owl:Class>
```

```
<!-- http://xmlns.com/foaf/0.1/OnlineChatAccount -->
<owl:Class rdf:about="&foaf;OnlineChatAccount">
<rdfs:label>Online Chat Account</rdfs:label>
<rdfs:subClassOf rdf:resource="&foaf;OnlineAccount"/>
<rdfs:comment>An online chat account.</rdfs:comment>
<ns:term_status>unstable</ns:term_status>
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1"/>
</owl:Class>
<!-- http://xmlns.com/foaf/0.1/OnlineEcommerceAccount -->
<owl:Class rdf:about="&foaf;OnlineEcommerceAccount">
<rdfs:label>Online E-commerce Account</rdfs:label>
<rdfs:subClassOf rdf:resource="&foaf;OnlineAccount"/>
<rdfs:comment>An online e-commerce account.</rdfs:comment>
<ns:term_status>unstable</ns:term_status>
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1"/>
</owl:Class>
<!-- http://xmlns.com/foaf/0.1/OnlineGamingAccount -->
<owl:Class rdf:about="&foaf;OnlineGamingAccount">
<rdfs:label>Online Gaming Account</rdfs:label>
<rdfs:subClassOf rdf:resource="&foaf;OnlineAccount"/>
<rdfs:comment>An online gaming account.</rdfs:comment>
<ns:term_status>unstable</ns:term_status>
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1"/>
</owl:Class>
<!-- http://xmlns.com/foaf/0.1/Organization -->
<owl:Class rdf:about="&foaf;Organization">
<rdfs:label>Organization</rdfs:label>
<rdfs:subClassOf rdf:resource="&foaf;Agent"/>
<ns:term_status>stable</ns:term_status>
<rdfs:comment>An organization.</rdfs:comment>
<skos:scopeNote xml:lang="en">Ued to describe an organization related to bibliographic items such as a publishing company,
etc.</skos:scopeNote>
<rdfs:isDefinedBy rdf:resource="http://xmlns.com/foaf/0.1"/>
</owl:Class>
<!-- http://xmlns.com/foaf/0.1/Person -->
<owl:Class rdf:about="&foaf;Person">
<rdfs:subClassOf rdf:resource="&foaf;Agent"/>
</owl:Class>
<!--
////////////////////////////////////
//
// Annotations
//
////////////////////////////////////
-->
<rdf:Description rdf:about="http://rdfs.org/sioc/spec">
<rdfs:label>SIOC Core Ontology Specification</rdfs:label>
</rdf:Description>
</rdf:RDF>
<!-- Generated by the OWL API (version 3.5.1) http://owlapi.sourceforge.net -->
```

Appendix B

SoIS OWL Ontology

<?xml version="1.0"?>

```
<!DOCTYPE rdf:RDF [  
  <!ENTITY owl "http://www.w3.org/2002/07/owl#" >  
  <!ENTITY xsd "http://www.w3.org/2001/XMLSchema#" >  
  <!ENTITY rdfs "http://www.w3.org/2000/01/rdf-schema#" >  
  <!ENTITY rdf "http://www.w3.org/1999/02/22-rdf-syntax-ns#" >  
>
```

```
<rdf:RDF xmlns="http://memorae.hds.utc.fr/sois#"  
  xml:base="http://memorae.hds.utc.fr/sois"  
  xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"  
  xmlns:owl="http://www.w3.org/2002/07/owl#"  
  xmlns:xsd="http://www.w3.org/2001/XMLSchema#"  
  xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#">  
<owl:Ontology rdf:about="http://memorae.hds.utc.fr/sois"/>
```

```
<!--  
////////////////////////////////////  
//  
// Object Properties  
//  
////////////////////////////////////  
-->
```

```
<!-- http://memorae.hds.utc.fr/sois#mc2:aboutClass -->
```

```
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#mc2:aboutClass">  
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#sois:ReferenceKey"/>  
  <rdfs:range rdf:resource="&owl;Class"/>  
</owl:ObjectProperty>
```

```
<!-- http://memorae.hds.utc.fr/sois#mc2:belongsTo -->
```

```
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#mc2:belongsTo">  
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Organization"/>  
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:user"/>  
</owl:ObjectProperty>
```

```
<!-- http://memorae.hds.utc.fr/sois#mc2:containsAgent -->
```

```
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#mc2:containsAgent">  
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Agent"/>  
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Organization"/>  
</owl:ObjectProperty>
```

```
<!-- http://memorae.hds.utc.fr/sois#mc2:hasAccount -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#mc2:hasAccount">
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Account"/>
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:user"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#mc2:hasSpaces -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#mc2:hasSpaces">
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Account"/>
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Space"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#mc2:hasTarget -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#mc2:hasTarget">
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Annotation"/>
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:IndexKey"/>
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Vote"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#mc2:index -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#mc2:index">
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:IndexKey"/>
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#sois:ReferenceKey"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#mc2:isVisibleFor -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#mc2:isVisibleFor">
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:IndexKey"/>
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Space"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#mc2:ownResource -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#mc2:ownResource">
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Resource"/>
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:user"/>
</owl:ObjectProperty>
```

```
<!-- http://memorae.hds.utc.fr/sois#sois:containAccounts -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#sois:containAccounts">
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Account"/>
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#sois:LeaderSystem"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#sois:containResource -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#sois:containResource">
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Resource"/>
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#sois:StandAloneApplication"/>
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#sois:WebBasedApplication"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#sois:hasReference -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#sois:hasReference">
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Resource"/>
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#sois:ReferenceKey"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#sois:reasons -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#sois:reasons">
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Vote"/>
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#sois:Activity"/>
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#sois:ResourceRecommendation"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#sois:useSystem -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#sois:useSystem">
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#mc2:user"/>
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#sois:InformationSystem"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#sois:utilize -->
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#sois:utilize">
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#sois:Activity"/>
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#sois:ReferenceKey"/>
</owl:ObjectProperty>

<!-- http://memorae.hds.utc.fr/sois#sois:viewResource -->
```

```
<owl:ObjectProperty rdf:about="http://memorae.hds.utc.fr/sois#sois:viewResource">
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Resource"/>
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#sois:LeaderSystem"/>
</owl:ObjectProperty>
```

```
<!-- http://www.w3.org/2002/07/owl#equivalentClass -->
```

```
<owl:ObjectProperty rdf:about="&owl;equivalentClass">
  <rdfs:range rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Activity"/>
  <rdfs:domain rdf:resource="http://memorae.hds.utc.fr/sois#sois:Activity"/>
</owl:ObjectProperty>
```

```
<!--
////////////////////////////////////
//
// Classes
//
////////////////////////////////////
-->
```

```
<!-- http://memorae.hds.utc.fr/sois#mc2:Account -->
```

```
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:Account"/>
```

```
<!-- http://memorae.hds.utc.fr/sois#mc2:Activity -->
```

```
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:Activity"/>
```

```
<!-- http://memorae.hds.utc.fr/sois#mc2:Agent -->
```

```
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:Agent">
  <rdfs:subClassOf rdf:resource="http://xmlns.com/foaf/0.1/Agent"/>
</owl:Class>
```

```
<!-- http://memorae.hds.utc.fr/sois#mc2:Annotation -->
```

```
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:Annotation">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Resource"/>
</owl:Class>
```

```
<!-- http://memorae.hds.utc.fr/sois#mc2:IndexKey -->
```



```
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:IndexKey"/>

<!-- http://memorae.hds.utc.fr/sois#mc2:Organization -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:Organization"/>

<!-- http://memorae.hds.utc.fr/sois#mc2:Person -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:Person">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Agent"/>
</owl:Class>

<!-- http://memorae.hds.utc.fr/sois#mc2:Resource -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:Resource"/>

<!-- http://memorae.hds.utc.fr/sois#mc2:Space -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:Space"/>

<!-- http://memorae.hds.utc.fr/sois#mc2:Vote -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:Vote">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Resource"/>
</owl:Class>

<!-- http://memorae.hds.utc.fr/sois#mc2:user -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#mc2:user">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Person"/>
</owl:Class>

<!-- http://memorae.hds.utc.fr/sois#sois:Activity -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#sois:Activity"/>

<!-- http://memorae.hds.utc.fr/sois#sois:DBIdentifier -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#sois:DBIdentifier">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#sois:ReferenceKey"/>
```

```
</owl:Class>

<!-- http://memorae.hds.utc.fr/sois#sois:HTMLTag -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#sois:HTMLTag">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#sois:ReferenceKey"/>
</owl:Class>

<!-- http://memorae.hds.utc.fr/sois#sois:HashTag -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#sois:HashTag">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#sois:ReferenceKey"/>
</owl:Class>

<!-- http://memorae.hds.utc.fr/sois#sois:InformationSystem -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#sois:InformationSystem">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#mc2:Agent"/>
</owl:Class>

<!-- http://memorae.hds.utc.fr/sois#sois:LeaderSystem -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#sois:LeaderSystem">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#sois:InformationSystem"/>
</owl:Class>

<!-- http://memorae.hds.utc.fr/sois#sois:ReferenceKey -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#sois:ReferenceKey"/>

<!-- http://memorae.hds.utc.fr/sois#sois:ResourceRecommendation -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#sois:ResourceRecommendation"/>

<!-- http://memorae.hds.utc.fr/sois#sois:StandAloneApplication -->
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#sois:StandAloneApplication">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#sois:InformationSystem"/>
</owl:Class>

<!-- http://memorae.hds.utc.fr/sois#sois:WebBasedApplication -->
```

```
<owl:Class rdf:about="http://memorae.hds.utc.fr/sois#sois:WebBasedApplication">
  <rdfs:subClassOf rdf:resource="http://memorae.hds.utc.fr/sois#sois:InformationSystem"/>
</owl:Class>
```

```
<!-- http://www.w3.org/2002/07/owl#Class -->
```

```
<owl:Class rdf:about="&owl;Class"/>
```

```
<!-- http://xmlns.com/foaf/0.1/Agent -->
```

```
  <owl:Class rdf:about="http://xmlns.com/foaf/0.1/Agent"/>
</rdf:RDF>
```

```
<!-- Generated by the OWL API (version 3.5.0) http://owlapi.sourceforge.net -->
```

Appendix C

MEMORAeSoIS User Guide

In order to understand how MEMORAeSoIS works, we take the following step-by-step scenario to show the user experience and illustrate the functionalities of the platform.

This user guide presents screenshots of taken from the application of the web-based systems with open API.

The first thing you need to do to use the platform is to have an account. The account follows our semantic model presented in the previous chapter. The user account has one or more organization, and in each organization we can find the sharing spaces of that account. All the information related to a user account (user profile, login credentials, organizations, sharing spaces) is stored as semantic triples in the Virtuoso triple store.

The login interface is shown in (Fig. [C.1](#)).

After logging in, the user can choose one of the organizations that he/she have access to. By choosing an organization the user chooses which map will be displayed. Each organization is stored in Virtuosos with all the concepts of its map as well. The choice of organization is shown in (Fig. [C.2](#)).

The Map is presented in tree view format. The root node is selected by default, and two subsequent levels are shown. To travel through the map you can click on any visible node. This will automatically change the focus to the newly selected node and the map will expand accordingly. Another way to go directly to any node is to search for it by starting to type the concept name in the search bar and select it from there.

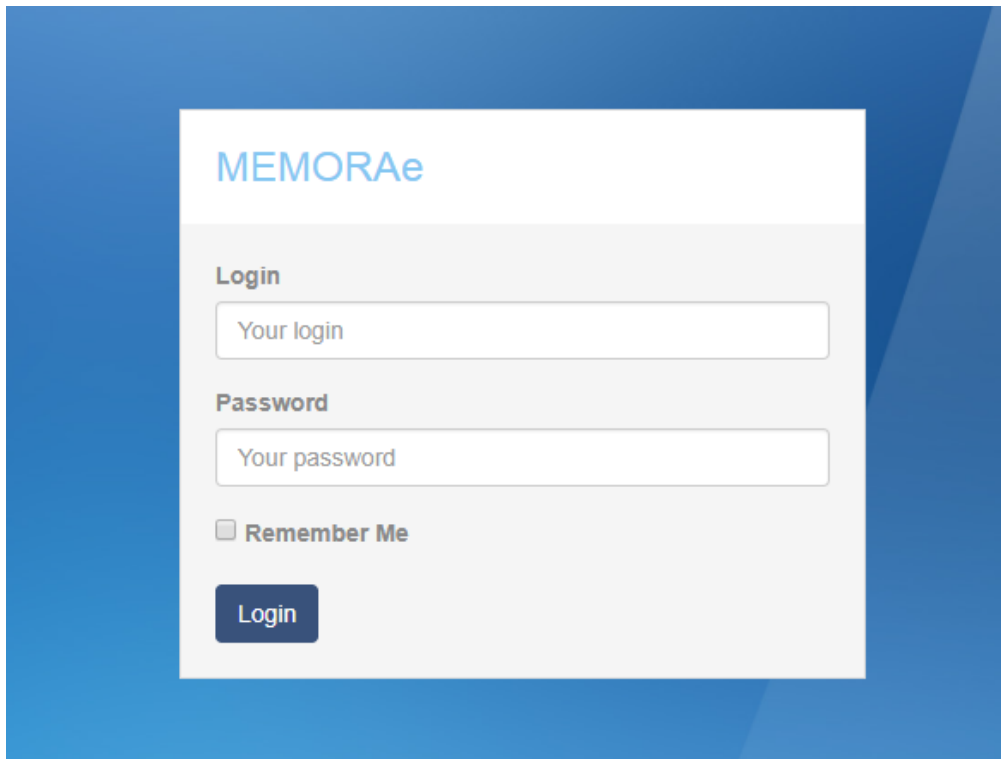


FIGURE C.1: Login interface.

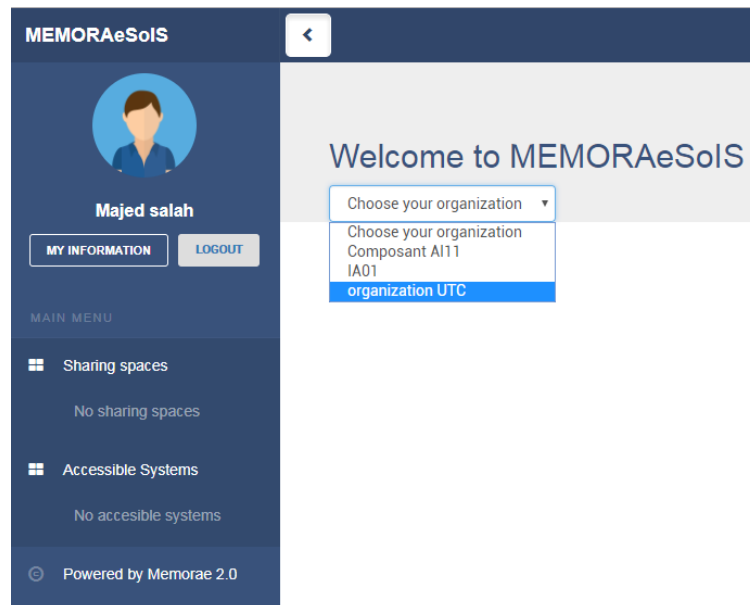


FIGURE C.2: Choose your organization.

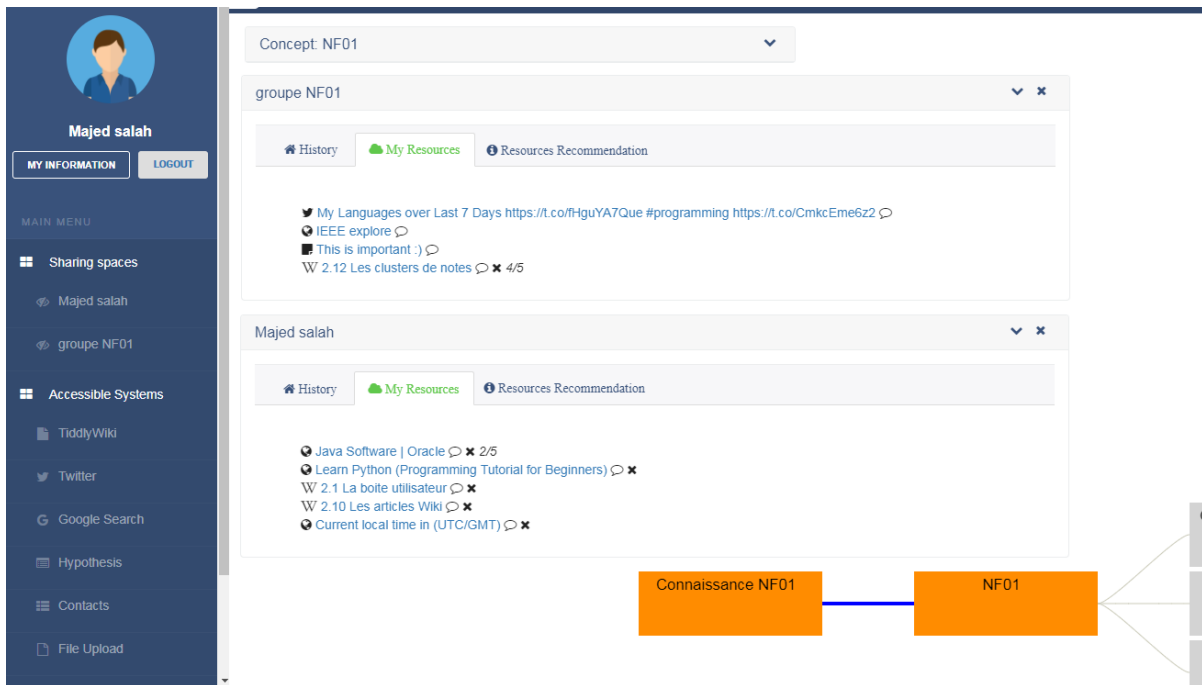


FIGURE C.3: Open sharing spaces.

Sharing spaces are the place where a user can share different types of resources with other users. Each user has at least two work spaces; one personal work space (named after the user), and one global workspace shared among all the users of the same organization. A user can open a work space to view its content, the resources which are shared in the sharing space, by clicking on it. To close a sharing space the user can click again on its name to toggle it off, or click on the close button in the open sharing space. As seen in (Fig. C.3), the user can open more than one sharing spaces. Each one of the sharing spaces holds different set of resources indexed by the focus node.

Now, the user wants to participate to the work flow and add resources of his/her own. For the sake of this scenario we will take the example of adding a note from Microsoft OneNote system. First the user has to click on the system to open new window that shows the resources of that system as in (Fig. C.4). If the external system requires authentication the user will be asked at this point to provide his/her login credentials for the external system (Microsoft OneNote in this case). After that, the user will see the list of resources that are available in the external system, as seen in (Fig. C.5).

To share a note or a notebook from Microsoft OneNote click on the share button next to the resource. The sharing window will pop up (Fig. C.6). Select the index and sharing space. Be aware that the user can select multiple indexes and work spaces.

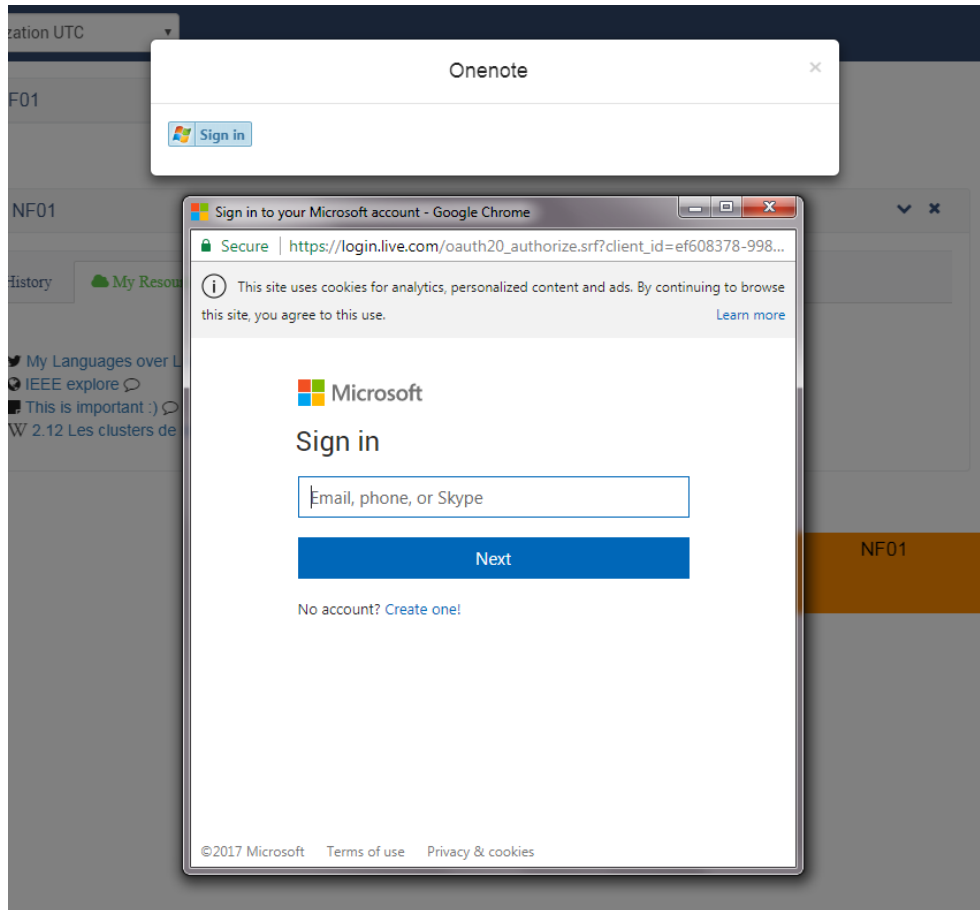


FIGURE C.4: Login to Microsoft OneNote.

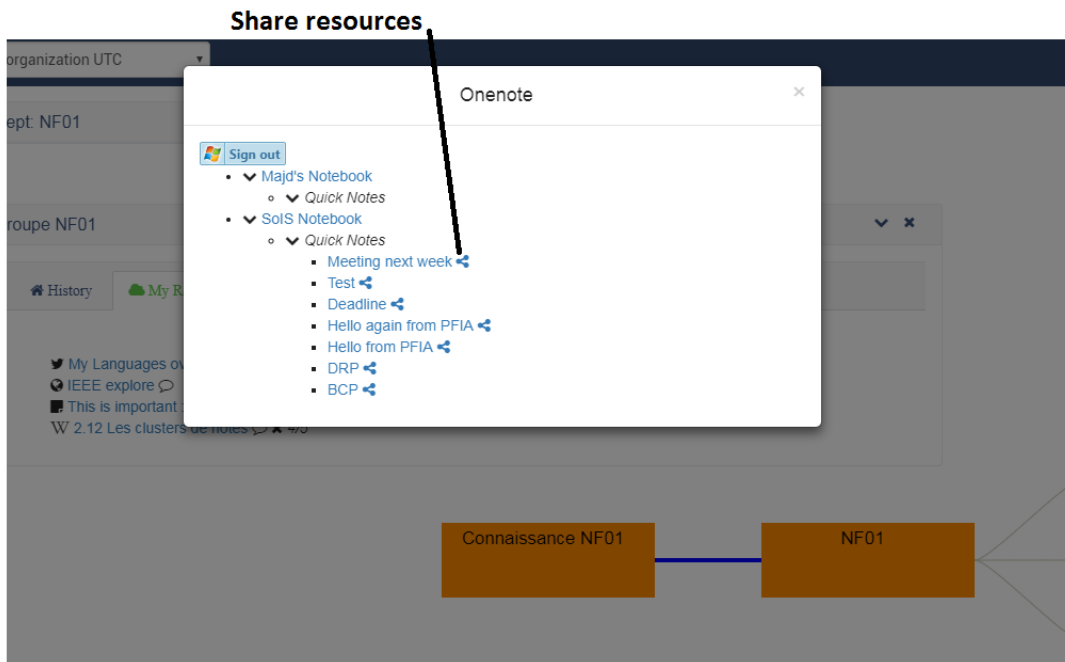


FIGURE C.5: All the resources available in the OneNote system.

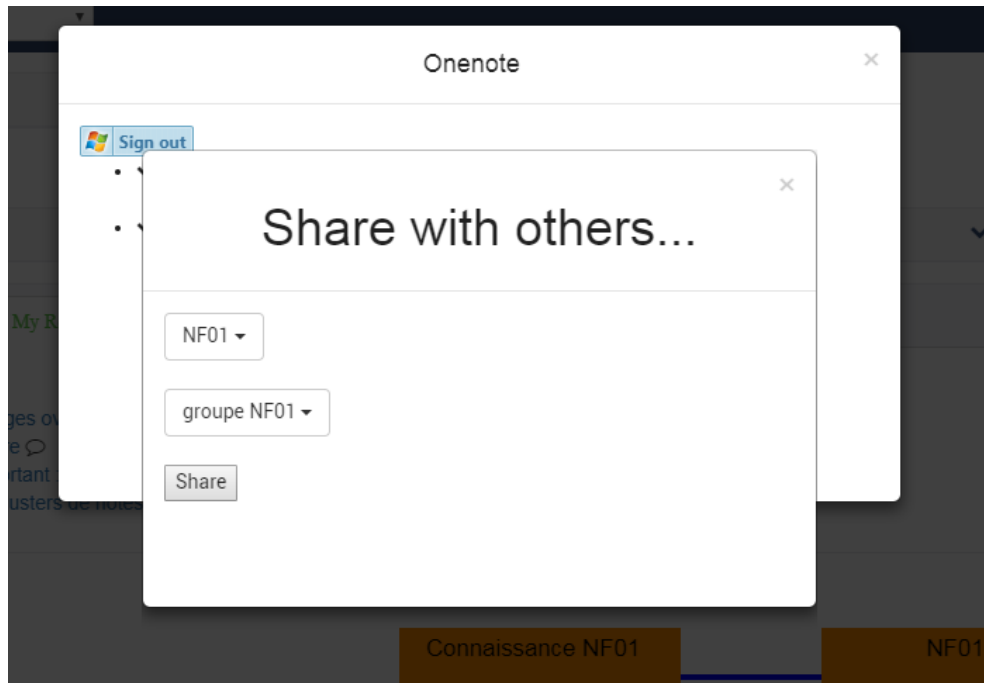


FIGURE C.6: Share and index a note from OneNote system.

In (Fig. C.7) we can see the note that has been shared in the sharing space "Group NF1" and indexed by the node "NF01". The user who added the resource is entitled to delete the resource using the cross sign next to the resource. Also we can see that the delete sign is present only next to some resources as the rest have been added by other users.

There are three main tabs in each sharing space. The first is the history tab where all the user activities are shown for each sharing space independent from the focus node. This tab shows activities like sharing, commenting, voting, deleting, navigating through the map, and accessing resources. The history tab is shown in (Fig. C.8).

The third tab in the sharing space is to view the resource recommendations. In this tab the user can see the resources recommended for him/her in this sharing space and indexed by the focus node. This is illustrated in (Fig. C.9), where we can see that the recommender system recommends two resources for the user. Each one of these resources has a score based on the recommendation algorithm. It is clear that one has a higher score, therefore, it is highly recommended for this user.

Now we look closer at how resources are represented in MEMORAeSoIS and how the link is made between Microsoft OneNote system and the MEMORAeSoIS. According to the definition of resources in the semantic model, resources are divided into simple

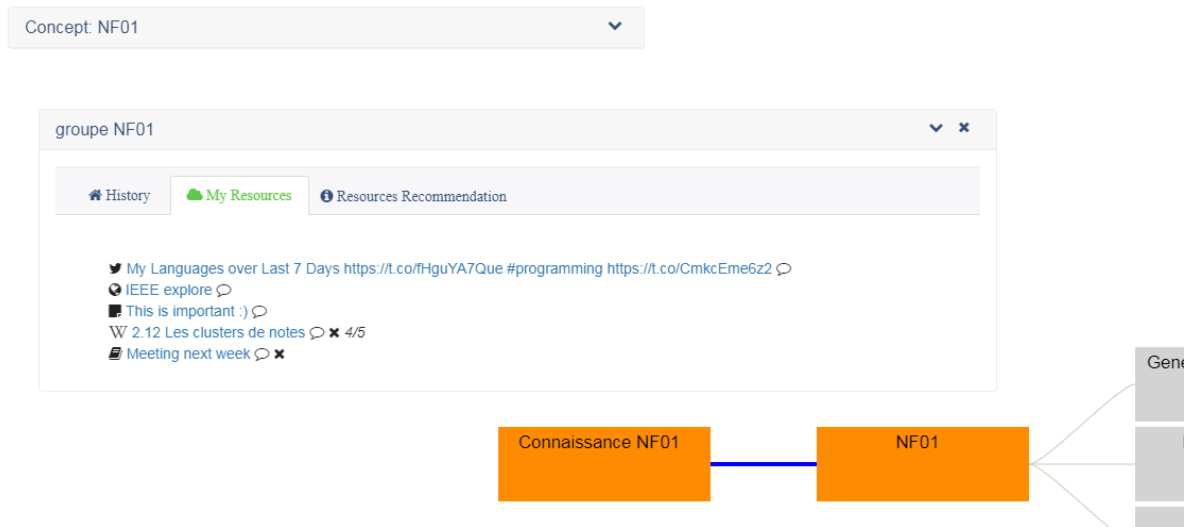


FIGURE C.7: The note shared in a sharing space and indexed by the focus node.

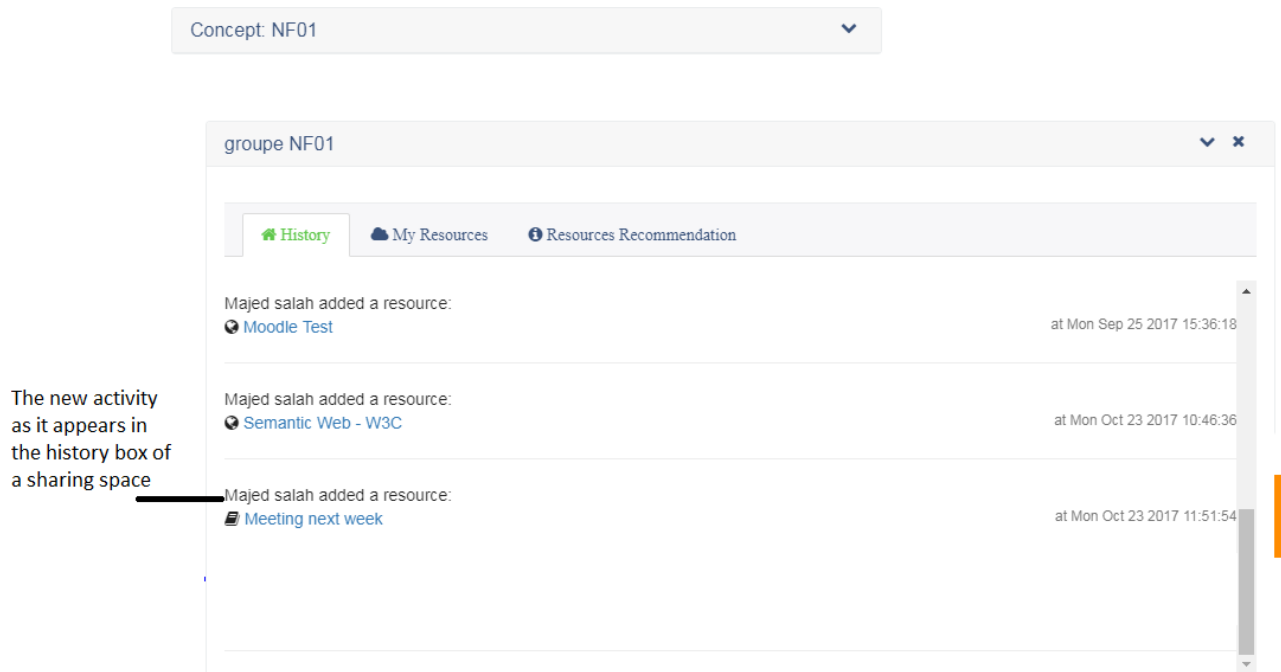


FIGURE C.8: History tab showing the activities of users in this sharing space.

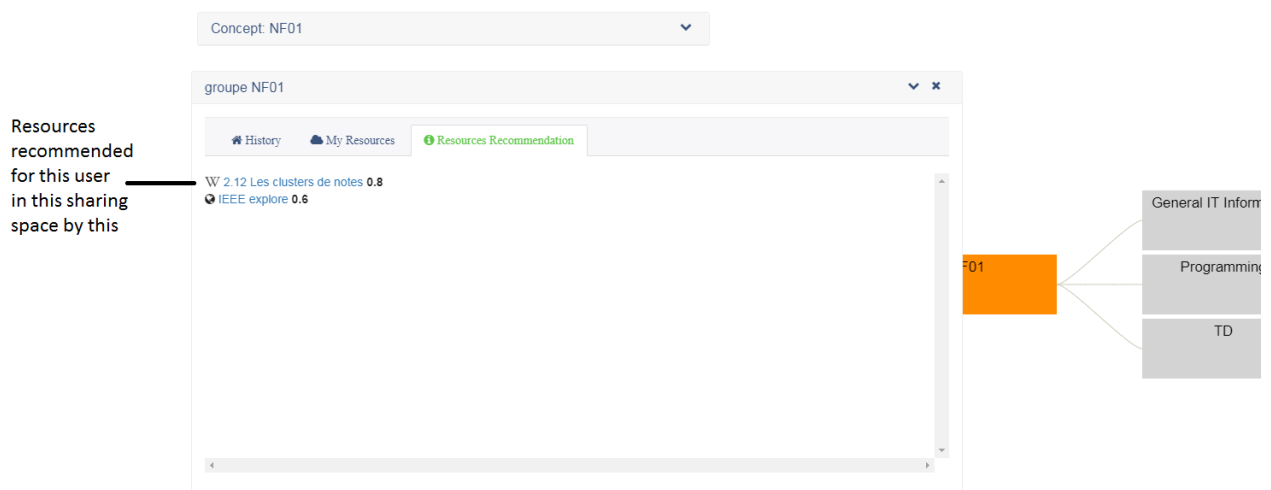


FIGURE C.9: Recommendation tab showing the recommended resources in this sharing space.

and complex resources. We consider the resources in the SoIS to be simple resources. They are only references to the real resources residing in their respected systems. To be more clear, MEMORAeSoIS needs the following information about external resources to store in Virtuoso: Resource name, resource link, resource type, resource handler (resource handler is not necessarily the resource creator as the resource can be created by someone in its respected system and then added to MEMORAeSoIS by someone else. Also, resource handler must have an account in MEMORAeSoIS, while the resource creator is not obliged to have one. In fact, the resource creator might not even now the MEMORAeSoIS exist but he/she gave permission to the resource to someone with access to MEMORAeSoIS), addition date, sharing space, and index. To reach the resource itself in its respected system we follow the architectural model, and the guidance by the second layer. Here, for Microsoft OneNote, we use the API provided by Microsoft developer center. The server queries OneNote system through the API and keeps the leader system informed with any new resources added to the external system by applying the observer pattern over websocket technology.

Regarding web annotations, MEMORAeSoIS uses a tool called Hypothesis to highlight and annotate parts on web pages. The steps to highlight or annotate with hypothesis are illustrated in (Fig. C.10) and (Fig. C.11). To annotate a part of a web page, first the user has to open the web page by clicking on it either from the work space or from the web links box. If hypothesis plugin is not activated it should be activated at this point. The user then can highlight the part he/she wants to annotate, and then

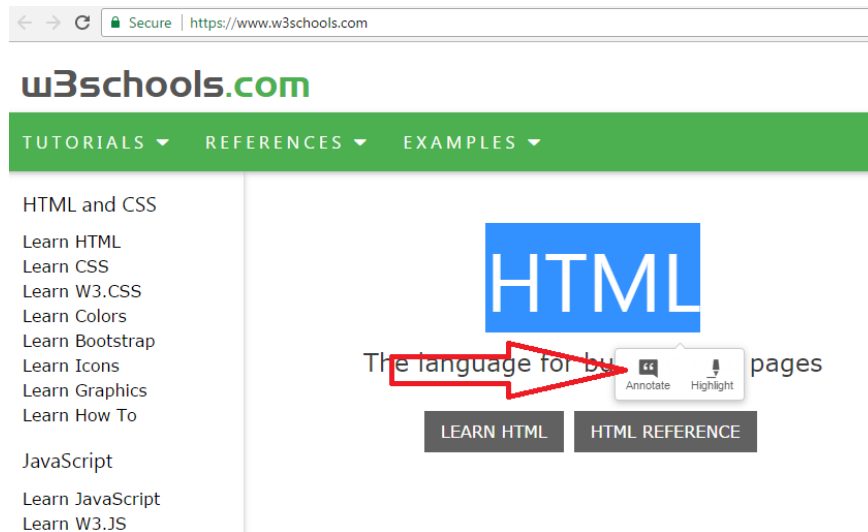


FIGURE C.10: Web Annotation with Hypothesis - part1.

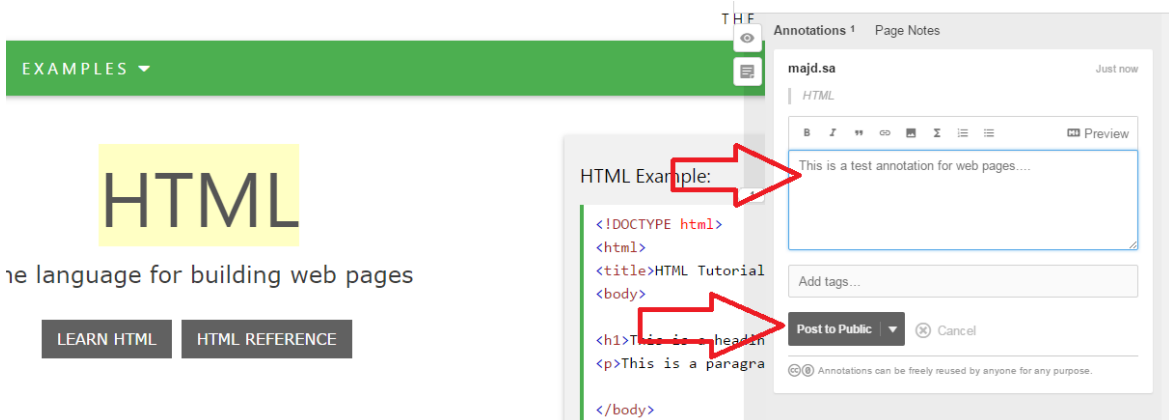


FIGURE C.11: Web Annotation with Hypothesis - part2.

click on the annotation button. The annotations realized by Hypothesis can be found in MEMORAeSoIS and can be treated respectively as resources. That means they can be shared and indexed separately from their web pages as independent resources. This gives the user the liberty to index a web page in one node of the map, and index an annotation about a part of this page in another node that he/she deems suitable for the annotated part. The web annotation as resources are viewed in MEMORAeSoIS as seen in (Fig. C.12)

The user can vote on resources and add comments by clicking on the bubble icon next to a resource in a sharing space. The user can choose a score (1 to 5) from the dropdown list, and then click the vote button. He/she can also add a comment about this resource to justify the vote. The average of votes by different users is shown

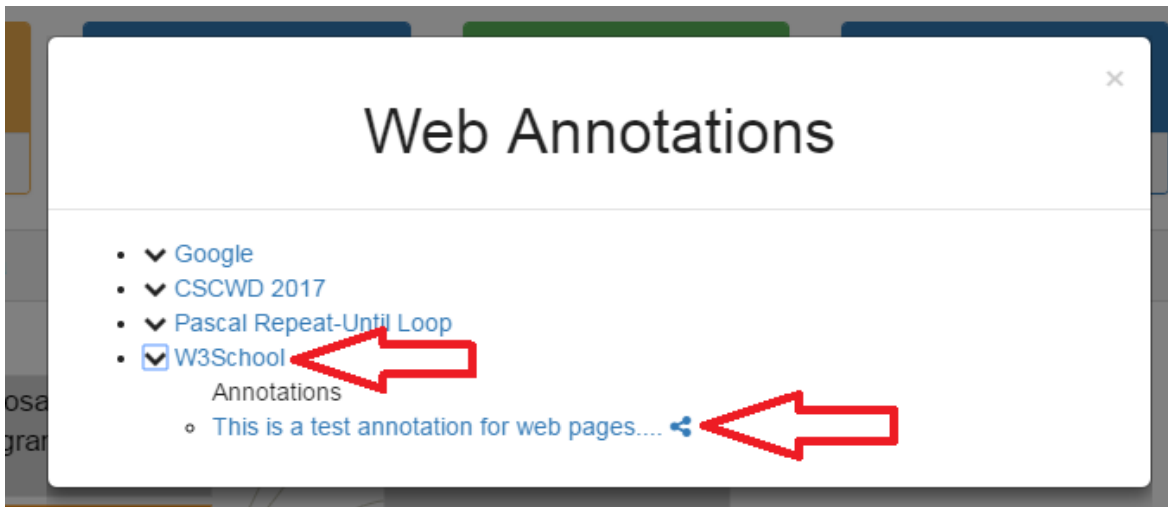


FIGURE C.12: Web Annotation with Hypothesis - part2.

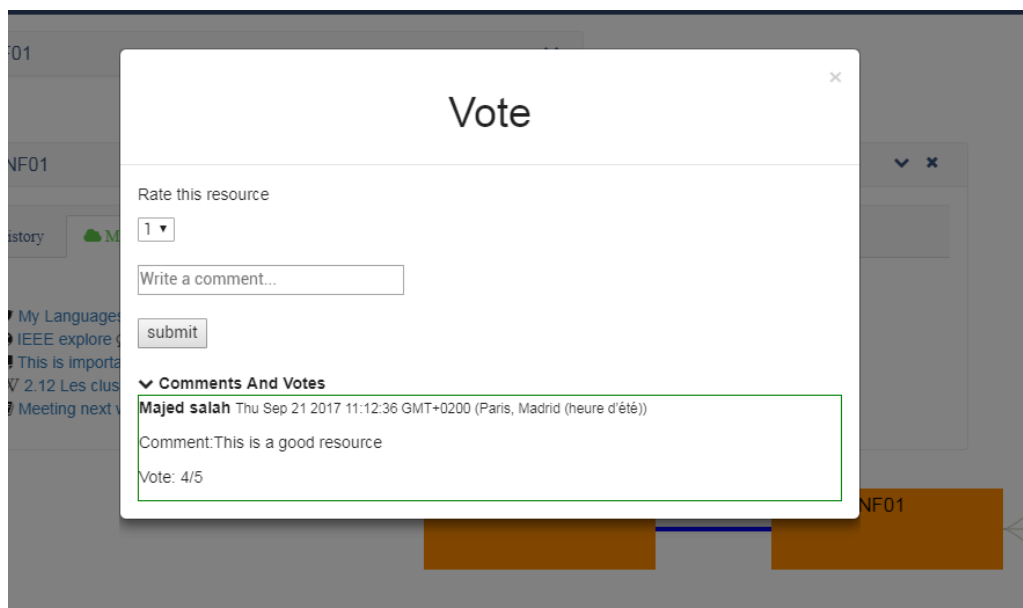


FIGURE C.13: The vote and comment window.

next to the resource in the sharing space. The user can consult individual votes and comments for each resource from the voting window of that resource. See (Fig. C.13).

Appendix D

Survey Questions

MEMORAeSols Test d'utilisabilité

* Required

1. Nom *

2. Prénom *

Fonctionnalités liées à la carte

3. La visibilité des concepts sur la carte est satisfaisante! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) *

4. La navigation la carte est facile et claire!(Réponse de 0 à 10, une décimale est permise, exemple : 7,9) *

5. Les concepts de la carte couvrent les sujets du cours de manière satisfaisante! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) *

6. La carte facilite l'organisation des ressources de manière satisfaisante! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) *

7. Il est nécessaire d'ajouter plus de concepts à la carte pour couvrir les sujets du cours! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) *

8. Commentaires

Fonctionnalités liées aux les espaces de partage

9. Les espaces de partage sont satisfaisants! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) *

10. L'organisation des espaces communs est satisfaisante pour trouver vos ressources! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) *

11. Avoir un espace de partage personnel est utile! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) *

12. Avoir un espace de partage pour les notes du cours est utile! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) *

13. **Avoir un espace de partage pour le cours est utile! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) ***

14. **Commentaires**

Fonctionnalités liées aux ressources

15. **Il est facile de partager mes ressources avec mes collègues sur MEMORAeSoIS! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) ***

16. **Il est facile d'indexer les ressources sur la carte! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) ***

17. **La fonctionnalité de vote et de commentaire est utile! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) ***

18. Commentaires

Utilité de la plate-forme web comme support de cours

19. **MEMORAeSolS aide à organiser vos ressources pédagogiques de manière satisfaisante! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) ***

20. **MEMORAeSolS à partager vos ressources pédagogiques de manière satisfaisante! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) ***

21. **MEMORAeSolS permet de travailler facilement en collaboration avec d'autres! (Réponse de 0 à 10, une décimale est permise, exemple : 7,9) ***

22. Commentaires
