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Applying Multi-Agent Software System to Support Citywide Mobile Learning

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"Many times a day I realize how much my own life is built upon the labours of my fellowmen, and how earnestly I must exert myself in order to give in return as much as I have received" -- Albert Einstein

"If I have seen farther than others, it is because I was standing on the shoulders of giants." -- Isaac Newton

Dedicated to my parents, wife & siblings

Abstract

Mobile Learning is an emerging mode of learning, in which a learner can use his/her mobile device to learn anywhere and any time. The immature and diverse field of Mobile Learning holds a blooming future and promises great benefits for the learners. Therefore, both researchers as well the industry are experimenting with different applications of Mobile Learning through pilot projects to evaluate its effectiveness.

Citywide Mobile Learning is a specialized form of Mobile Learning, in which a mobile learner can use his/her mobile device to learn, while [s]he is moving around in the city. To provide technological support for such form of learning, sophisticated supporting systems are required. A major challenge is the dynamic environment of cities that consist of mobile learners and a number of locations. A system designed to provide support for Citywide Mobile Learning shall be constructed using technological components that can manage the dynamic environment.

In this thesis, our main goal is to provide support for Citywide Mobile Learning where the main subject of learning is to *learn about the city by being in it*. To reach this goal we overview the patchy literature of Mobile Learning to extract central characteristics of Mobile Learning in general and Citywide Mobile Learning in particular. To organize and analyze different locations in the city we adopt the theoretical notions of Space, Place and Learning-Experience. These theoretical notions are mapped into a Multi-Agent framework called AGORA. AGORA is extended to provide specialized support for Citywide Mobile Learning. Based on the important characteristics of Citywide Mobile Learning two important technological artefacts are derived. Firstly, a framework consisting of Service-Model and AGORA based Multi-Agent System is created. Secondly, an ontology is created that attempts to capture all the concepts and relationships relevant for Citywide Mobile Learning. More particular contributions of this thesis are as follows:

C1: Providing a framework for supporting mobile learning in a citywide context
C2: Using the philosophical concept of *Place* to structure and organize different locations in the city to support mobile learning
C3: Applying the theories related to *Place* and *Experience* into practice by extending Multi-Agent framework called AGORA
C4: Representing the concepts related to *Space/Place* based mobile learning in the form of ontology. This ontology captures the knowledge related to Mobile User, Learning Groups, Learning *Space*/*Place*, and Learning-Tasks
C5: Identifying the core patterns of Citywide Mobile Learning

Preface

This thesis is submitted to the Norwegian University of Science and Technology (NTNU) for partial fulfilment of the requirements for the degree of philosophiae doctor.

This doctoral work has been performed at the Department of Computer and Information Science, NTNU, Trondheim, with Professor Mihhail Matskin as the main supervisor and with Professor Monica Divitini and Professor Rolv Bræk as co-supervisors.

Acknowledgements

I am grateful to The Lord, who gave me powers, energies and abilities to complete this work.

I would like to sincerely thank my main supervisor, Professor Mihhail Matskin, who was always there to guide me throughout this work. Even though he is a busy person, he was always prompt to provide feedback, advice and comments. I always learned something new from the discussions we had. I feel myself very lucky to have such a cooperative and understanding person as supervisor who had a clear vision about my work. I would also like to thank Professor Monica Divitini for all the support she provided for completing this work. She has been extremely supportive and understanding, her comments and suggestions were always helpful. Her charming and cooperative personality was itself a morale booster and it was always very easy to drop by her office and discuss work related issues with her. I am thankful to Professor Rolv Bræk for participating in the meetings and providing his valuable comments.

A special thank you goes to my colleagues at IDI, particularly to those with whom I shared my office for four years. Thanks to Mamdouh, Ilaria, Chiara and Surya for being so nice and kind, the conversations and joint discussions we had were really valuable. I also acknowledge the role of Sobah and Anders, who provided suggestions to improve the quality of my work. I am particularly thankful to the secretaries Norun, Anna, Birgit and others who took care of all the managerial issues, while I was able to concentrate on my work.

Thanks to my loving wife, parents (especially my father), siblings and mother-in-law who were always there to help and support me. Thanks for being understanding and cooperative, when I was absorbed in my work and was not able to give you enough time. Your precious love and encouragement kept me going. A special thank you to Dr. M.Saleem Khan who has supported me throughout me academic career. I am thankful to Asad Malik for helping me to proof read this thesis.

I acknowledge the role of the Norwegian research council and NTNU, who provided the necessary funds and environment to complete this work.

Finally, I would like to thank all my family, friends, and colleagues near or far, who I cannot mention because of limited space.

viii

Contents

List of Figures

List of Tables

Abbreviations

FABULA   FremrAgende By for Undervisning og LAering – (Translated into English as) Seamless networks for transforming the city into an arena for Learning

AGORA   AGent Oriented Resource mAnagement

ML   Mobile Learning

CML   Citywide Mobile Learning

FFC-ML   FABULA Framework for Citywide - Mobile Learning

MAS   Multi-Agent System

F-MAS   FABULA Multi-Agent System

SAP   Service Access Points (SAP)

IDE   Integrated Development Environment

PART I -- Introduction and Overview

Chapter 1

Introduction

This work demonstrates the design, application and usefulness of Multi-Agent System (MAS) to support Mobile Learning **(ML)** in non-formal settings such as cities. In order to establish and explore relationship between learner[1] and the learning environment we have adopted the notions of *Space*[2] and *Place*[3] [see chapter 5]. This particular approach permits us to capture core aspects of ML in a citywide context. From a theoretical standpoint we identify how a learner carrying a mobile device can gain knowledge about different *Space*s in the city and how this knowledge influences the future activities of the learner in the same *Spaces*. From a technical point of view we adopt a two-step process. During the first step we develop a platform called ***FABULA Framework for Citywide Mobile Learning (FFC-ML)*** *(A. B. Khan & Matskin, 2009; 2010)* consisting of services and ***FABULA Multi-Agent System (F-MAS)***. The FFC-ML allows us to take note of all the main requirements for a ML system that can operate in a citywide context. Key features of the FFC-ML are pro-activeness and autonomous behaviours. In the second step we translate and put into operation the hierarchical relationship between the city and different *Space*s present in the city; this functional support is constructed over the FFC-ML developed during the first step. In doing so we construct an ontology to capture the static and dynamic properties and relationships relevant for ML in citywide context.

The work presented in this thesis is anchored at the junction of three main cords. Firstly, considering *City as the context for ML*, secondly *structuring city as a collection of Spaces on top of which we render the notion of meaningful Place to support **Citywide Mobile Learning (CML)***. Lastly, to *devise a Multi-Agent (System) based service platform* that can deliver services to support CML based on the conceptualization of *Space*s/*Place*s. The last two parts of our work presents the major underpinning of this thesis, where we go beyond the physical and spatial aspects of *Space*s in the city to explore and apply the philosophical conceptualization of *Place*s as a layer of meanings. In this regard we consider Casey's (Casey, 1993; 1998) elucidation of *Place*, which treats *Place* as a dynamic concept; perception of which is different for different individuals and its understanding continues to be reconstructed and restructured based on individual's experience of it. The vibrant concept of *Place* is considered dynamic

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[1] The terms user, learner and people have been interchangeably used throughout this thesis, all these terms refer to the concept of **Mobile Learner** in the citywide context

[2] Since the word "*Space*" represents a special meaning in the context of this thesis, therefore throughout this thesis it appears in italic fonts with first the letter in upper case

[3] Since the word "*Place*" represents a special meaning in the context of this thesis, therefore throughout this thesis it appears in italic fonts with first the letter in upper case.

based on the movement and experience of individuals (i.e. learners). FFC-ML reflects the two major perspectives of the FABULA system. FFC-ML's *Passive perspective* defines the main services required to support ML, while the active perspective (F-MAS) looks at the system from a dynamic point of view and uses the AGORA Multi-Agent framework (Matskin, Kirkeluten, Krossnes, & Sæle, 2000; Niu, Matskin, & B. Zhang, 2007). To assimilate the notion of *Space/Place* and provide automated support for CML to different number and types of learners we extend **AGent Oriented Resource management (AGORA)** Multi-Agent framework (A. B. Khan & Matskin, 2010a; 2011a; A. B. Khan, Matskin, & Chiara Rossitto, 2011). Extended AGORA framework allows us to capture the dynamic aspects of user's mobility and *Space/Place* conceptualization. In conjunction with *Space/Place* and AGORA we also propose different patterns of AGORAs to support common ML scenarios in citywide learning context.

1.1. Motivation and Scope

> *"The number one benefit of information technology is that it empowers people to do what they want to do. It lets people be creative. It lets people be productive. It lets people learn things they didn't think they could learn before, and so in a sense it is all about potential"* -- **Steve Ballmer**.

Information technology has changed the way we work, live, communicate and understand our surroundings. We are forced to live in the world that is influenced by the technology. Soon enough we find ourselves floating in the cyber space. "*These altered traditional, objective categories of place and time have changed the way we present the world to ourselves"* (Harvey, 1991). The term *technological determinism* is believed to be coined by the Norwegian-American sociologist named "Thorstein Bunde Veblen" (1857-1929)[1]. According to his view, the ultimate driving force for human development is technology. To put it more simply *"technology determines human behaviour, social relations and indeed, social organization itself"* (Cope & Kalantzis, 1999). For the cultures, tools, languages, lifestyles, businesses, communication and/or education systems, technology plays an integral part.

All these changes are based on the observations of our changing world; *"where phones are carried everywhere, banks are accessed from holes in the wall, cars are becoming travelling offices, airplane seats are entertainment centres, computer games are handheld, and advertising is ubiquitous"*(Sharples, 2006a). With the emergence of new technologies our societies have also evolved to cope with the changing atmosphere of digital climate. Technological-society, Technological-age and Mobile-era are some of a few buzzwords that have caught a lot of attention and are being debated heavily in the research community. Such societies integrated with state of the art technologies open up a number of opportunities and challenges.

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[1] http://en.wikipedia.org/wiki/Thorstein_Veblen

1.1 Motivation and Scope

In such a fluid and rapidly changing environment, learning new skills and gaining knowledge is not an option, but a supreme priority. Therefore, *"[.....] more learning needs to be done at home, in offices and kitchens, in the contexts where knowledge is deployed to solve problems and add value to people's lives"* (Leadbeater, 2000). Such form of informal *ML* is not just limited to learning activities involving teachers and students, but can also take place among learning peers who want to learn from each other; by performance of shared tasks, through social networking and by participating actively in learning activities (Canova Calori & Divitini, 2009). Furthermore, such learning may emerge in an unplanned and ad-hoc manner through interaction, exploration and serendipity (Canova Calori, 2009).

The dream of a personal device for learning (Kay, 1972) that was once speculated as a science fiction story is now a reality. A new paradigm of technology-enriched societies are individuals who are *transfused* with the technology. Highly influenced by the mainstream technologies of today, these individuals carry sophisticated and high-end mobile devices in their pockets and purses. They are identified by Axel Bruns (Bruns, 2007) as **Generation C** and Lars Løvlie (Løvlie, 2006) called them **Cyborg**. The availability of such subjects already creates grounds for facilitating ML. It is now tremendously important to engage Generation C / Cyborg into informal forms of ML. "*Public engagement (actual and virtual) generates knowledge and exchange of experiences on various levels which in turn are the object of academic interest, research and knowledge production"* (Cope & Kalantzis, 1999).

Opportunities are *here and now*. The need of the hours is a new epistemology, which "*must account for the burgeoning, variety of text forms associated with information and multimedia technologies"*(Cope & Kalantzis, 1999). A natural context for such form of ML are cities, where the wireless networks are ubiquitously available and opportunities for learning are scattered over the geographical boundaries in the form of interesting locations to learn about and relevant peers to learn from. However, supporting such form of learning is radically different form traditional E-Learning Systems (e.g. BlackBoard[1], Fronter[2], FirstClass[3]), where the main goal is to deliver the learning content to the learner. The prevailing situation requires *"[...] networked tools that support and encourage individuals to learn together while retaining individual control over their time, space, presence, activity, identity and relationship"* (T. Anderson, 2005).

In order to cater for the ML that occurs in cities a new breed of learning support systems is required. Among others, these systems shall be able to support three fundamental aspects

1. Structure of different learning *Space*s in the cities
2. Dynamic nature of mobile learner in terms of movement and learning needs

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[1] http://www.blackboard.com/
[2] http://uk.fronter.info/
[3] http://www.firstclass.com/

3. Active support to encourage learning activities in the absence of direct supervision

Such a system will take into account both technical and pedagogical aspects of learning. It will provide supporting services (functional units) and mechanisms (intelligent decision making units) to conduct learning activities. It should consider the fact that a teacher might not always be part of learning process and may not always be available to a learner. It is important that the learning system participates actively and intelligently during the learning activities while dealing with the challenges such as open, heterogeneous and dynamic environment of cities. In this way the system should not only act as a passive medium of pre-defined communication patterns, but it also should perform an active role to increase the learning outcome. This should be done by following and assisting the learner throughout the learning process through recommendation and filtering of relevant learning material, by understanding and evaluating the contextual learning *Space* of learner and adjusting the system's behaviour accordingly and thereby personalizing the learning experience for each individual learner.

The traditional classroom based form of formal learning involving teacher and students also needs to be adopted. However, we limit the scope of this thesis by focusing only on the informal form of ML, which takes place in informal settings such as a city.

1.2. Problem Domain and Research Questions

The main context of this work is *"FremrAgende By for Undervisning og LAering" – translated as "Seamless networks for transforming the city into an arena for Learning"* FABULA project (Bræk, 2007; FABULA, 2007). The FABULA project work plan divides the project into 7 work packages. The work presented in this thesis partially accounts for the work done for four different work packages (**WP**s), namely WP1 (Conceptual framework), WP2 (Design), WP3 (Development framework) and WP4 (Delivery platform). The main objectives of FABULA's WPs that we took into consideration are summarized as follows (FABULA, 2007):

o *"[…] focus will be on learning experiences outside the classroom, situated in a city, acknowledging that learning comes from exploration, interaction, and serendipity"*

o *"[….] explore the design space of learning services in the city and structure this space [….]"*

o *"[…] develop generic service oriented architecture for situated, mobile e-learning [...]"*

o *"[…] providing an infrastructure that, […], supports the seamless integration of different learning experiences [...]"*

o *"[…] main concerns are "novel principles and technical solutions" for collaborative and location aware learning activities using mobile networks"*

o *"[…] conceptual and technical tools [….] to develop proof-of-concept applications"*

Guided by the context of FABULA the problem domain and primary research questions for this thesis are positioned at the intersection of theory and its application in the real world. Figure **1** provides an overview of all the aspects that are considered relevant for this thesis. Central to our investigation is to *translate different theoretical explanations (i.e. Space/Place and experience) and use them for supporting CML by applying a Multi-Agent System*. In doing so FFC-ML is designed, FF-CML defines the Service-Model and F-MAS is required to support CML; Service-Model consists of different levels and categories of services. Furthermore, an ontology is designed and implemented to structure and capture the domain knowledge relevant to CML.
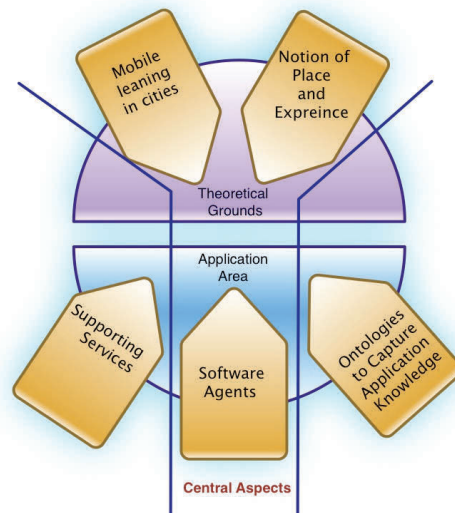
Figure 1: Problem domain for this thesis

In light of the above discussion, the main research question for this thesis is: **"*How can mobile learning about a city that consists of different interesting locations be supported by the technology through applying Multi-Agent System and services provisioning"*.**

More specifically

RQ1: *Are there any theoretical foundations that can be use to model a city consisting of many sub-physical structures to support informal and situated mobile learning?*

RQ2: *How can the "learning experience" which occurs in the city, be represented and used in a technological solution to provide a supporting mechanism for citywide mobile learning?*

RQ3: *What are the different categories of service required to support citywide mobile learning?*

RQ4: *How and in what form Multi-Agent System could be used to support mobile learning in a dynamic environment where the learning needs and location of learner are subject to frequent changes?*

RQ5: *What are the concepts, relationships, and patterns (i.e. configurations) that are relevant to CML, which must be represented in the domain ontology?*

1.3. Main Aim

The broad aim of this thesis is to bridge the gap between theory and application in information technology. Although we have provided a thorough account of all theoretical aspects relevant to this work, we are however leaning more towards the issues related to technical support required to enable ML in cities. Therefore, our main aim is to show that the approach we have adopted is useful for CML and can be used in practice. However, because of time limitation, experimentation and evaluation against a large amount of field data measuring the pedagogical aspect of this work is not our primary concern. It is important to underline that this does not mean that our work is not evaluated. The evaluation of this work is based on typical use case scenarios. With the help of these scenarios we show that after performing different "Learning-Tasks" a mobile learner does learn about the city and his/her knowledge about the city improves. Using these cases we also demonstrate practical feasibility of our ideas. Furthermore, we show that our system provides sufficient technical support for a pedagogical expert who will use the system to evaluate ML outcome.

1.4. Research Design and Publications

The overall design of this research can be broken down into four main phases where each phase corresponds to the work performed to achieve a particular sub-goal. The adopted research approach is threefold, namely it has theoretical, conceptual and empirical components. As shown in Figure **2**, the first phase of this work was dedicated to developing an understanding of theoretical foundations. During this phase we mainly focused on the theoretical aspects of ML and the *Place* as a conceptual notion to represent meanings associated with different locations in the city. During this phase we also establish the main requirements for supporting CML. Building on output from the first phase, during the second phase we developed the framework (FFC-ML) to support ML in cities. The conceptual framework served as an analytical lens to guide the later phases of this work. During the third and fourth phases, the abstract understanding was

translated into more detailed concepts and it was implemented in order to demonstrate our ideas. This was also related to the empirical aspect of our work.
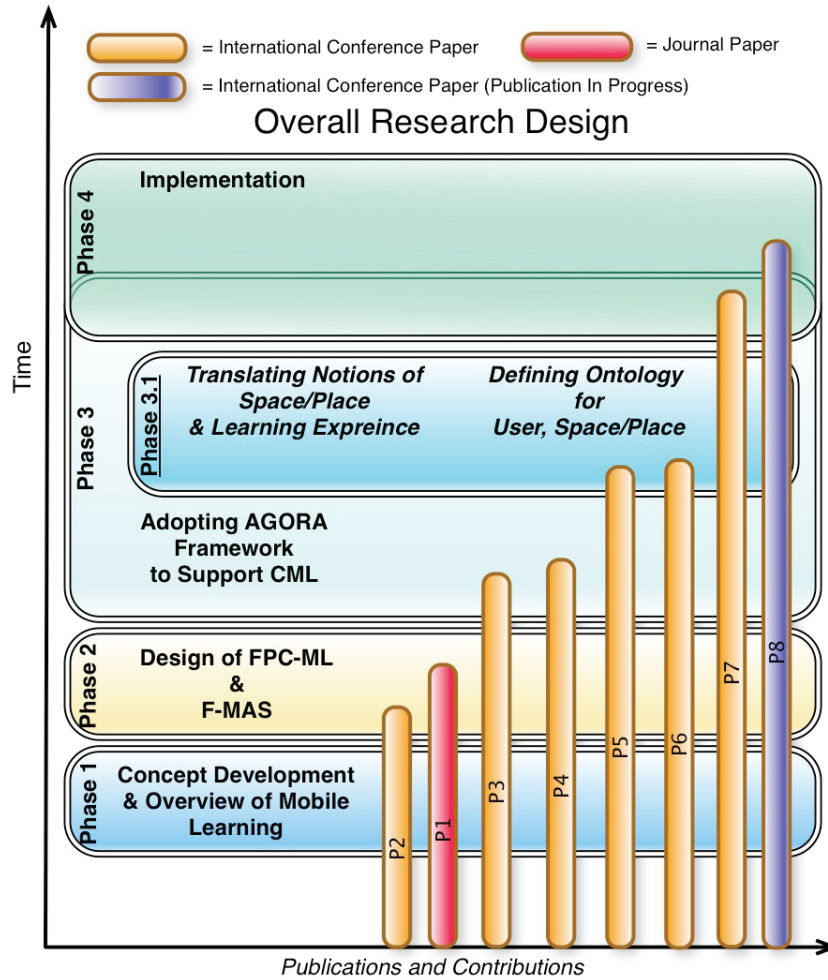
Figure 2: Overall research process

Work presented in this thesis was published at both national and international levels. The international publications appeared in a journal and in conference proceedings. Figure **2** shows the number of international publications directly relevant to this work, the height of each publication column depicts the time when it was published and its relevance to each phase of this work. Later sections provide a detailed account of major publications presented in Figure **2**. Other activities during the course of this work include two master theses' (Donate, 2010; Parmiggiani, 2010) which I co-supervised in cooperation with my supervisors and writing *"FABULA project's work package plan"* (B. A. Khan, Canova Calori, Kathay, & Eljudi, 2009) edited in cooperation of other colleagues.

1.4.1. Publications in Journals

P1 Khan, A.Basit., and Matskin, M., (A. B. Khan & Matskin, 2010). A Platform for Actively Supporting e-Learning in Mobile Networks. Parsons, D., editor. International Journal of Mobile and Blended Learning (IJMBL 2010). Issue 1. Volume 2. Pages 55-79. ISSN 1941-8647. IGI Global.

Abstract: *The ubiquitous availability of wireless networks has opened new possibilities for individuals to learn from each other in open learning spaces like cities. Therefore, the changed learning environment must be understood by e-learning systems and technological facilities must be provided for knowledge sharing and construction. Such systems need to be pedagogically sound, yet adaptive to altered modalities. The teacher who was once the central entity to fulfil the learner's needs may not always be available. Therefore, e-learning systems would fill the gap created by this teacher unavailability by actively participating in learning activities and performing some of the teacher's roles. This paper proposes an architecture designed to meet such challenges in a city-wide context. The authors outline the main components and services needed to fulfil the new requirements and provide the learners with tools, services and educational support for learning activities.*

Relevance to this thesis: *Building on the output of the first paper (**P2**) this paper presented an extended overview of the e-learning frameworks. The description of FFC-ML became very detailed in this paper. It defined in very fine details the types, roles, responsibilities and service provided by each AGORA of F-MAS. This paper provided a detailed view of FFC-ML, which is a very important result of this work.*
My Contribution: *under the competent guidance of my main supervisor, I am the first author of this paper.*

1.4.2. Publications in International Conferences

P2 Khan, A.Basit., and Matskin, M., (A. B. Khan & Matskin, 2009). FABULA Platform for Active e-Learning in Mobile Networks. Sánchez, I. A., Isaías, P., editors. Proceedings of the IADIS International Conference Mobile Learning (2009), Barcelona, Spain. Pages 33-41. ISBN 9789728924775. IADIS Press.

Abstract: *Connectedness has become a common term of today's world. The ever-increasing availability of network access has opened new possibilities for individuals to collaborate and share information with one another. With the communication infrastructure in place software support can be used to describe, publish and discover the learning resources. An individual carrying a mobile device has the opportunity to get access to a dynamic and collaborative environment full of similar individuals. In such an environment there is a huge potential to learn from others through sharing of experiences and conducting shared tasks. Learning methodologies can take significant advantage of the capabilities of information technologies and can take the learning experience a step further. However there is still a great need of e-learning systems, such systems can make use of*

communication infrastructure. This paper is written within the scope of project FABULA. By the virtue of this paper we present the work done to construct a service based e-learning architecture for FABULA system. This architecture uses Web-services and software agents to support efficient collaboration and cooperation for learning activities.

Relevance to this thesis: *This paper presented our first step to design a framework to support mobile learning (FFC-ML). It looked at different e-learning frameworks and presented our framework, which considered software-agents (i.e. AGORA) as a core building block. The framework we presented in this paper laid the foundation for our work.*

My Contribution: *under the competent guidance of my main supervisor, I am the first author of this paper.*

P3 Khan, A.Basit. and Matskin, M,. (A. B. Khan & Matskin, 2010a). AGORA Framework for Service Discovery and Resource Allocation. Bellot, G. O., Hideyasu, S., Ehmann, M., Dini, C., editors. The Fifth International Conference on Internet and Web Applications and Services ICIW(2010), Barcelona, Spain. Pages 438-444. ISBN 978-0-7695-4022-1. IEEE Computer Society Press.

Abstract: *Integration of Web Services and agent technology is still a problem which needs to be solved. Several different approaches have been proposed and demonstrated, however the solutions proposed are mainly targeted to translation of standards. We believe that the main problem is not translation of standards, but to use different standards together. In this paper we propose a radically different approach to achieve interoperation. Instead of performing translation we propose a framework which focuses on using different kind of services (Including Web Services) and agents together. Our proposed framework supports well known standards and is able to support future changes. By virtue of this work we try to solve three different problems. Firstly we provide a solution which unifies different standards, secondly we propose an agent framework which is capable to adapt to changes and evolve in open environment and lastly we adopt a peer-to-peer service discovery and invocation in our framework. Our agent framework is general enough to adapt to any problem and the existing implementation of our framework can be extended/over ridden without any need to change the core concepts.*

Relevance to this thesis: *This paper redefined the structure and internal workings of the AGORA framework to support mobile learning. The concepts relevant to mobile learning which were developed during this paper, play a big role during the implementation phase. Our demonstration overarches AGORA framework to provide support for mobile learning. The concept of AGORA also played a primary role when we mapped the notion of Spaces/Places to AGORAs.*

My Contribution: *under the competent guidance of my main supervisor, I am the first author of this paper.*

P4 Khan, A.Basit., and Matskin, M., (A. B. Khan & Matskin, 2010b). Towards an Engineering of Multi-Agent Eco-Systems. Hussain, F., K., Chang, E., editors. Conference Proceedings of 4th IEEE International Conference on Digital

Ecosystems and Technologies (2010) Dubai, United Arab Emirates. Pages 340-345. ISBN 978-1-4244-5553-9. IEEE Press.

Abstract: Different approaches for engineering Multi-Agent Systems have been proposed over time. However, there is a lack of attention towards the social aspects of Multi-Agent systems. In this paper we present an approach for engineering multi-agent systems, which considers multi-agent systems as digital ecologies. Different agent ecologies can work together to act as digital ecosystem, in such an ecosystem the social aspects of the agents are well defined and all the subcomponents of the multi-agent system work together to achieve a fine integration of the whole ecosystem. Instead of focusing on the internal model of software agents our methodology attempts to capture the dynamic and social behaviours of agents by focusing on the cooperation, coordination, negotiation and management attributes of the system. From an implementation point of view, the proposed engineering methodology is grounded in our multi-agent framework and the concepts developed using this methodology can easily be mapped to implementation. The framework provides support integration of web-services and uses a peer-to-peer approach for resource discovering.
Relevance to this thesis: This paper presents the agent engineering approach, which we have used to develop the F-MAS. With the help of this approach it is possible to take into account the dynamic aspects (coordination, communication and negotiation) involved to support CML. F-MAS developed using this approach is instantiated and used for the demonstration of use cases.
My Contribution: under the competent guidance of my main supervisor, I am the first author of this paper.

P5 Khan, A.Basit., and Matskin, M., Rossitto, C., (A. B. Khan et al., 2011). Towards a Places and Spaces based city-wide mobile learning through multi-agent support. Hussain, F., K., Chang, E., editors. Proceedings of the 5th IEEE International Conference on Digital Ecosystems and Technologies Daejeon, Korea. Pages 164-169. ISBN 978-1-4577-0872-5. IEEE Press.

Abstract: This paper illustrates how the conceptualization of Places can be used to inform the technical design of mobile learning systems. We apply the concept of Place in a multi-agent framework for supporting informal city-wide mobile learning activities. By taking input from the theoretical framework for analysing collaborative learning activities, we adopt the structure and organization of multi-gent framework. The functionality and components of the system are defined in light of the theoretical work. This work bridges the gap between theory and its application in technology for mobile learning in our project.
Relevance to this thesis: This paper presents the initial ideas to map the notion of Place into AGORA multi-agent system. Work presented in this paper combines the theoretical perspective with the implementation. This paper also contributes towards the development of the ontology to support CML.
My Contribution: under the competent guidance of my main supervisor, and expert advice of "Chiara Rossitto" I am the first author of this paper.

P6 Khan, A.Basit., and Matskin, M., (A. B. Khan & Matskin, 2011a). Multi-agent system to support Place/Space based mobile learning in city. Charles A. Shoniregun, Galyna Akmayeva. Proceedings of International Conference on Information Society (i-Society 2011), London, United Kingdom. Pages 66 - 71. ISBN 978-0-9564263-8-3. IEEE Press.

Abstract: Different approaches have been developed to provide technical support for mobile learning. Most of these approaches consider only the physical properties of the learning environment. In this work, we not only focus on the physical/spatial dimension of the learning environment of the city, but also pay attention to the notion of Place which is a meaningful outcome of peoples understanding of Space. This paper illustrates how a theoretical conceptualization of Spaces and Places is mapped into a multi-agent framework called AGORA. It presents the design aspects of a mobile learning system, which uses software agents as its core functional units. We discuss how the theoretical concepts are used to define a technical solution to support mobile learning in a citywide context.
Relevance to this thesis: Building on the output of previous paper. This paper presents the detailed mapping of Space/Place into the AGORA framework. It also discusses the different types of FABULA users. Another very important result of this paper is that it translates theoretical conceptualization of "learning experience" into an implementable concept. This paper illustrated different types of "learning experiences" which were added into our system's ontology.
My Contribution: under the competitive guidance of my main supervisor, I am the first author of this paper.

P7 Khan, A.Basit., and Matskin, M., (A. B. Khan & Matskin, 2011b). GUMO Inspired Ontology to Support User Experience Based Citywide Mobile Learning. Proceedings of 2nd International Conference in User Science and Engineering (i-USEr), Malaysia. IEEE Press.

Abstract: User experience has been extensively discussed in literature, yet the idea of applying it to explain and comprehend the conceptualization of Mobile Learning (ML) is relatively new. Consequently much of the existing works are mainly theoretical and they concentrate on establishing and explaining the relationship between ML and experience. Little has been done to apply or adopt it into practice. In contrast to the currently existing approaches, this paper presents an ontology to support Citywide Mobile Learning (CML). The ontology presented in this paper addresses three fundamental aspects of CML, namely User Model, User Experience and Places & Spaces which exist in the city. The ontology presented here not only attempts to model and translate the theoretical concepts such as user experience and Place/Spaces for citywide context for Mobile Learning, but also apply them in practice. The discussed ontology is used in our system to support Place/Space based CML.
Relevance to this thesis: The translated concepts of Space/Place and learning experience provided in P6 resulted in the implementation level details of theoretical concepts. However, all the different chunks were fragmented. This paper put together all the different concepts of CML into ontology. Thereby, it provided a

clear and coherent view of all the relevant concepts with the relationships among them clearly defined. Apart from combining all the concepts for CML into ontology, the major contribution of this paper was user-model of the mobile learner. This user-model presented in this paper was inspired by a popular and very generic user model called GUMO. The result presented in this paper further elaborates the implementation detail, the user-model presented in this paper served as a way to take into account the important aspect related to the mobility of the mobile learner, while ignoring the other less important ones.
My Contribution: under the competitive guidance of my main supervisor, I am the first author of this paper.

P8 Khan, A.Basit., and Matskin, M. (2012), Supporting Place/Space Based Patterns of Citywide Mobile Learning Through Multi-Agent Framework. 7th IEEE International Conference on Wireless, Mobile & Ubiquitous Technologies in Education. Takamatsu, Kagawa, Japan. IEEE Press. **(Submitted for Review)**

Abstract: There are numerous possible patterns consisting of learners, technological components and physical locations (i.e. Spaces) which can be identified in the context of citywide mobile learning (CML). By patterns, we mean to refer to the different ways in which learners are associated with the Spaces where the learning occurs, with technology that supports learning and among the learners themselves. Envisioning the entire set of possible scenarios, which can exist in the citywide context and designing to support them is not only difficult, but also practically impossible. Therefore, there is a need to condense and generalize all the numerous possible scenarios of CML into few core patterns, which can be use as basic building blocks to construct and support more complex CML scenarios. A regular trend in the currently existing literature is to consider only one or two use-cases while neglecting others. In this paper we address this problem by presenting six general patterns instead of use-cases that can exist in citywide context. These patterns take into account three fundamental aspects of CML, (1) learner, (2) Place/Space and (3) the technological components needed to support CML.
Relevance to this thesis: This paper presents the six core patterns of Place/Space based CML. The patterns presented in this paper discuss possible configurations of learners, Place/Space and technological components. Using these core patterns it is possible to create more sophisticated configurations of learns, Place/Space and technology.
My Contribution: under the competitive guidance of my main supervisor, I am the first author of this paper.

1.4.3. Publications in Symposiums / National Conferences

P9 Khan, A.Basit., Canova Calori, I., Kathay, S. B., (B. A. Khan, Canova Calori, & Kathay, 2008). FABULA - THE CITY AS AN ARENA FOR LEARNING: THE TECHNICAL INFRASTRUCTURE. VERDIKT Conference 2008, Bergen, Norway. Pages 44-45.

P10 Khan, A.Basit., (A. B. Khan, 2009). Multi-agents to actively support city-wide collaborative learning. VERDIKT Conference 2009, Oslo, Norway. Pages 59.

P11 Khan, A.Basit., (A. B. Khan, 2010). Learning in City Through Multi-agent Support. Cerratto-Pargman, T., Hyvonen, P., Jarvela, S., Milra, M, editors. Book of abstracts -- The First Nordic Symposium on Technology Enhanced Learning (Norditel 2010), Växjö, Sweden. Pages 78-79.

1.5. Main Contributions

As discussed earlier, this work lean towards the application of theory in practice; therefore the contributions are more technical than theoretical. T main contributions of this thesis can be summarized as follows:

C1: Providing a framework for supporting mobile learning in a citywide context

C2: Using the philosophical concept of *Place* to structure and organize different locations in a city to support mobile learning

C3: Applying the theories related to *Place* and *Experience* into practice by extending the Multi-Agent framework called AGORA

C4: Representing the concepts related to *Space/Place* based mobile learning in the form of ontology. This ontology captures the knowledge related to Mobile User, Learning Groups, Learning *Space/Place*, and Learning-Tasks

C5: Identifying the core patterns of CML

Figure 3: Publications in relation to research questions and contributions

These contributions, as presented in this thesis along with the publication, provide answers to the research questions presented in section 1.2. Figure **3** depicts the relationship between research questions, contributions and publications. Position of each publication in Figure **3** informs about its significance in relation to the research question(s) it answers and the contribution(s) it makes.

1.6. Thesis Structure and Outline

This thesis is divided into four main parts. The first part named **"PART I -- Introduction and Overview"** provides an introduction to this work and consists of only one chapter named "Introduction". The second part named **"PART II -- Background and State of the Art"** provides a detailed account for the theories, concepts, tools and technologies relevant to this work. It consists of four chapters. The chapter named "Perspectives on Mobile Learning" provides an understanding of ML in relation to the city. The next chapter in PART II is named "Overview of Learning". This chapter provides an overview and analysis of existing platforms to support learning. The chapter named "Software Agents and Ontologies" provides an overview of software agent technology and ontologies. Finally, the fourth and last chapter named "Framework of *Places* and *Spaces*" provides the theoretical grounds for the notion of *Place* and establishes a relationship between *Space* and *Place*.

The third part of this work is named **"Part III -- Research Results"**, this part presents the major findings and results of the work. The third part consists of three chapters; first chapter is named "AGORA Based Citywide Mobile Learning Framework", this chapter presents the architecture of FABULA system to support ML and consists of "FABULA Platform for Citywide - Mobile Learning (FFC-ML)" and "FABULA Multi-Agent System (F-MAS)". The next chapter named "Articulating AGORA Support for *Space & Place* Based Mobile Learning" provides a detailed account of how the concepts of *Space*, *Place* and "Learning-Experience" are translated and mapped into our Multi-Agent framework called AGORA. It also provides an understanding of how the structure of a city is rendered into AGORA to support tasks related to support CML.

The last chapter of Part III, is named "Design and Implementation of Ontology & *Places/Spaces* Based Mobile Learning". It provides information about two main aspects of this work, firstly it presents FABULA-Ontology, secondly it informs about the implementation details. The last and final part of this thesis is named **"Part IV – Evaluation and Future Directions"** and consists of two chapters. A chapter named "Evaluation", evaluates the results of our work. This chapter also highlight the support available in our system to perform different types of analysis and evaluation of ML. The last chapter of this thesis named "Conclusion and Future Directions" discusses the future directions of this work and concludes this thesis.

Some contents of this thesis are taken directly from our research publications; IGI Global and IEEE are the copyright holders for that content. Copyright contents are used with the permission of IGI Global and IEEE, see Appendix D for details.

PART II -- Background and State of the Art

<div align="right">

Chapter 2

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Perspectives on Mobile Learning

> *Mobile technologies are becoming more embedded, ubiquitous and networked, with enhanced capabilities for rich social interactions, context awareness and internet connectivity. Such technologies can have a great impact on learning. Learning will move more and more outside of the classroom and into the learner's environments, both real and virtual, thus becoming more situated, personal, collaborative and lifelong. The challenge will be to discover how to use mobile technologies to transform learning into a seamless part of daily life to the point where it is not recognized as learning at all. (Lonsdale, G. N. Vavoula, Sharples, & Naismith, 2004)*

In this chapter we will provide an overview of the term *Mobile Learning* (ML) in relation to theory, technology and ambiguity that surrounds the topic. This chapter will set the frame in which all the other issues related to this thesis will fit. **Main aim**—of this chapter is to **introduce mobile learning** and to discuss its similarities and differences with **mobile learning in a city**.

2.1. Introduction to Mobile Learning

According to an estimate from *International Data Corporation* (IDC) (IDC - Press, 2011) the "smart phone" shipments made by the top five mobile phone manufacturers during 2010 were recorded as follows: *Nokia*[1] shipped 100.3 million, *Research In Motion*[2] shipped 48.8 million, *Apple*[3] shipped 47.5 million, *Samsung*[4] shipped 23 million and *HTC*[5] 21.5 million. All other manufacturers shipped 61.5 million smart phones during 2010. These figures indicate a mighty leap forward compared to 2002, when Microsoft predicted that the number of PDAs would be above100 million worldwide in 2002 (Microsoft Corp, 2001). Also, according to *International Telecommunication Union* (ITU) (mobithinking, 2011) during 2010, 120 mobile subscriptions were present per 100 people in Europe and the worldwide mobile operator's revenue will exceed from 1 trillion dollars during 2011 (Wehmeier, 2011).

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[1] http://www.nokia.com/
[2] http://www.rim.com/
[3] http://www.apple.com/
[4] http://www.samsung.com/se
[5] http://www.htc.com/

Chapter 2. Perspectives on Mobile Learning

As the number of available mobile devices is increasing the possibilities to utilize them for different constructive purposes are numerous. Mobile Learning (ML) is the form of learning that uses mobile devices as a medium/tool for learning and teaching. Considering the available number of mobile users the idea of ML does hold a blooming future. "*Mobile technologies is in itself a motivator to exploit them for learning*" (Lonsdale et al., 2004). However as we will discuss later, mobile devices represent only one aspect of overall conceptualization of ML. The traditional classroom based learning involving teachers and students can gain significant benefits from ML, however formal classroom-based learning blended with mobile devices is just a subset of ML. The application spectrum of ML is huge and under the umbrella of ML exist both formal and informal forms of learning.

The immature field of ML is developing at a very rapid speed (J. Traxler, 2005; 2007). As more and more new mobile devices are making their way to the consumer market, researchers have started to investigate their usefulness to support learning (Kukulska-Hulme, 2007; Sharples, 2000; 2006a). With the availability of these devices we are experiencing a shift in philosophical, theoretical and professional dimensions of learning (J. Herrington & A. Herrington, 2007). Table **1** summarizes the shifting dimensions of learning.

Table 1: Shift in philosophical, theoretical & professional dimensions of learning (J. Herrington & A. Herrington, 2007)

Dimension	Moving from		Moving to
Philosophy	Instructivist		Constructivist
Theory	Behaviorist, cognitivist		Situated, socio-constructivist, andragogical
Course design	Bounded scope and sequence		Open-ended learning environment, flexible content
Time and place	Fixed in educational institutions		Distributed, to suit the contexts of the learners
Knowledge base	'Objective' knowledge, largely determined by experts		Knowledge built and shared among the community
Tasks	Decontextualized, concise, self-contained		Authentic, reflective, complex and sustained
Resources	Fixed, chosen by teacher		Open, chosen by learners with access to search tools
Support	Teacher		Community of learners,
Mode	Individual, competitive		Collaborative, networked
Technology tools	Fixed, located in learning spaces		Mobile, portable, ubiquitous, available
Knowledge outcomes	Facts, skills, information		Conceptual understanding, higher order learning
Products	Academic essays, exercises, or no tangible product		Authentic artifacts and digital products
Assessment	Standardized tests, examinations		Performance-based, integrated and authentic assessment
Transfer of knowledge	Stable knowledge adapted to different contexts		New and changing knowledge acquired when required
Professional learning	Courses, group events, workshops		Personal, just-in-time, community-based

The shifting dimensions presented in Table **1** indicate that learning, which was once considered to only take place under formal settings such as schools, colleges and universities, is now moving outside these places into locations where learners are present. Knowledge and understanding is constructed through discussions and

conversations among the learning peers. The outcome of learning is no longer solution to homework, but absorption of knowledge in the form of new skills, which are reflected in the learner's everyday life. Based on shifts in the dimensions of learning the key rationale behind the idea of using mobile devices for learning is formulated by Sharples (Sharples, 2000; Sharples, Corlett, & Westmancott, 2002) as follows:

- o *"Learning is not confined to pre-specified times or places, but happens whenever there is a break in the flow of routine daily performance and a person reflects on the current situation, resolves to address a problem, to share an idea, or to gain an understanding"*

- o *"Formal education cannot provide people with all the knowledge and skills they need to prosper throughout a lifetime. Therefore, people will need continually to enhance their abilities, in order to address immediate problems and to participate in a process of continuing vocational and professional development"*

While the reality of ML is taking its time to equal the hype, "*visionaries believe mobile learning offers learners greater access to relevant information, reduced cognitive load, and increased access to other people and systems" (L.Koole, 2009).* In parallel to the emerging research body of ML there is a wide array of its application in other fields, Taxlor (J. Traxler, 2005) outlines a large number of ML applications. ML is applied in classroom (Johnson & Bhana, 2005; Perry, 2003; Zaitun & D. Singh, 2006) in higher education (Frohberg, 2004), in collaborative learning (Pinkwart, Hoppe, Milrad, & Perez, 2003), for counselling and guidance (Vuorinen & Sampson, 2003), in corporate training for mobile workers (Gayeski, 2002; Lundin & Magnusson, 2003; Pasanen, 2003), in medical education (O. Smørdal, 2003), for teacher training (Seppala & Alamaki, 2003), for music composition (Polishook, 2005), for nurse training (Kneebone, 2005), for language learning (Ogata et al., 2008; Chengjiu Yin et al., Ogata, 2006), for learning about the city (A. B. Khan & Matskin, 2011a; A. B. Khan et al., 2011), for visiting museums (Lepouras, Arnedillo Sánchez, & Isaías, Antoniou, 2008; Papadimitriou, Raptis, Yiannoutsou, Komis, & Avouris, Tselios, 2009), for social work (Oussena & Barn, 2009), for cultural understanding (Bennett & Arnedillo Sánchez, Maniar, 2007), and for many other fields. In general the major purpose of ML is to let people of all ages learn at all possible times through the use of available mobile devices. Thus, the goal of ML is to help the people to learn whatever they need at any stage of their lives; more people live longer, they need more knowledge to sustain their existence and keep up with the ever-changing environment of our societies.

2.2. Defining Mobile Learning

Despite the ever-increasing interest in ML there is no commonly accepted definition of ML. Even before we can attempt to define ML, we must first explain the two

constituting terms "mobility" and "learning". The dictionary[1] defines the term mobil*ity* as *"the ability to move or be moved freely and easily"* and learn*ing* as "*the acquisition of knowledge or skills through study, experience, or being taught"*. If we consider the combined dictionary definition of both these terms it would literally mean "*the acquisition of knowledge or skills through study, experience, or being taught while being able to move freely and easily*". However, the dictionary definition doesn't underlines the subject who is moving, this is to say that it is not clear if it is the learner who is moving or the device (i.e. technology)? The earlier ML literature also presents a similar state where authors tend to either place an emphasis on the mobility of involved technology (i.e. devices) or the mobility of learner (Savill-Smith, Attewell, & Stead, 2006). Below we present a few definitions from existing ML literature. The first set of definitions are centred around **mobile technology**, while the second set of definitions are centred around the **mobility of learner**.

Technology Centred Definitions
  o *The advent of mobile technologies has created opportunities for delivery of learning via devices such as PDAs, mobile phones, laptops, and PC tablets (laptops designed with a handwriting interface). Collectively, this type of delivery is called m-learning (Peters, 2007)*
  o *MLearning is the acquisition of any knowledge and skill through using mobile technology, anywhere, anytime, that results in an alteration in behaviour (Geddes, 2004)*
  o *The use of mobile devices in learning is referred to as mobile learning (Ally, 2004)*
  o *Any educational provision where the sole or dominant technologies are handheld or palmtop devices (J. Traxler, 2005)*
  o *MLearning is the intersection of mobile computing and e-learning: accessible resources wherever you are, strong search capabilities, rich interaction, powerful support for effective learning, and performance-based assessment. E-learning is independent of location in time or space(Quinn, 2000)*
  o *It is simply a new vehicle for delivering education to today's learners via mobile phones, PDAs, tablet PCs, etc (D. Clark, 2007)*
  o *The term mobile learning covers the personalised, connected and interactive use of hand held computers in classrooms (Perry, 2003)*
  o *The exploitation of ubiquitous handheld technologies, together with wireless and mobile phone networks, to facilitate, support, enhance and extend the reach of teaching and learning (MoLeNET, n.d.)*

Learner Centred Definitions
  o *Any sort of learning that happens when the learner is not at a fixed, predetermined location, or learning that happens when the learner takes advantage of the learning opportunities offered by mobile technologies* (O'Malley et al., 2003)

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[1] http://oxforddictionaries.com/

2.2 Defining Mobile Learning

- o *An obvious, yet essential, difference is that it starts from the assumption that learners are continually on the move (Sharples, Taylor, & G. N. Vavoula, 2005)*
- o *Mobile learning is not just learning using portable devices, but learning across contexts (Walker, 2006)*

From definitions presented above it is clear that the "mobility" is a fundamental aspect of ML and its importance cannot be denied or neglected. Both approaches to define ML have the same goal that is to uncover and understand the different phenomena associated with ML. One side of the picture is "*technology centred*" that considers ML from the standpoint of available technologies that can support it. While the other side is "*learner centred*" that considers the learner as the primary aspect of ML, while considering supporting technology as a secondary aspect.

In contrast to the previous definitions of ML, recent works in the field of ML present a unifying and more practical approach to define ML. For instance El-Hussein (El-Hussein & Cronje, 2010) provides a definition of ML which states that "*Mobile learning as an educational activity makes sense only when the technology in use is fully mobile and when the users of the technology are also mobile while they learn*". As another example (Clark & Quinn, 2009) write that "*An activity that allows individuals to be more productive when consuming, interacting, or creating information, mediated through a compact digital portable device that the individual carries on a regular basis and has reliable connectivity and fits in a pocket or purse*". Sharples and others take it a step further to define ML and discuss four different types of mobilities involved in ML. According to them (Sharples, Milrad, G. N. Vavoula, & Arnedillo-Sánchez, 2007) "*Research into mobile learning is the study of how the mobility of learners augmented by personal and public technology can contribute to the process of gaining new knowledge, skills and experience*". For them Learning is a cumulative process which disappears in time and is attributed by the following different types of mobilities:

- o **Mobility in physical space**: relates to the actual mobility of the learner in the physical space (i.e. changing position of learner)
- o **Mobility of technology:** related to the mobility of the device use for learning (i.e. change in the position of learning devices and the device itself)
- o **Mobility in conceptual space:** underlines the changing attention of learner which hops from one learning topic to another
- o **Mobility in social space:** relates to different social groups in which the learning occurs

In our view both *technology centred* and *learner centred* approaches to define ML are correct, but incomplete. Considering device and learner in isolation does not provides the complete view of ML's picture. Technology cannot exist without the learner and notion of learner without the support of technology does not exist within the scope of ML. Technology (i.e. device supporting learning) is the digital representation of the learner and thus the presence of device is actually the presence of the learner. In other words the device and the learner are fused together to form a singular personality. Thus, capabilities/affordance of device complements the capabilities of the learner. The functionality supported by device decides the possible learning scenarios that a learner

can make use of. Therefore, a view of ML that regards learner and device as a singular entity may be more useful. In the light of the above discussion ML may be defined as *any form of knowledge acquisition which occurs through the use of handheld mobile device which is carried by the learner whose position is not fixed relative to his/her physical or virtual surroundings*.

2.3. History of Mobile Learning

The history of ML is directly linked to the history of mobile devices and dates back to 1970s when Xerox[1] introduced Dynabook (Kay, 1972). This project proposed a portable device for helping children to learn. The proposed device can also be considered as the ancestor of today's portable computers and its invention directly led to the development of the personal computer (Sharples et al., 2007). The term "Personal Digital Assistant (PDA)" was coined by Apple and according to "Evan Koblentz" Hewlett-Packard's (HP)[2] programmable calculator, also developed during 1970, was the precursor of the PDA (D. Clark, 2007). The key year in the history of PDA was 1978 when Lexicon[3] sold its first handheld language translator called LK-3000 (Koblentz, 2009). However, it was during the 1990s when handheld device industry really took off and a number of capable devices that were easily programmable became commonly available.

History of ML can be divided in to three phases (Sharples, 2006b). These phases also depict the three different approaches to explain and understand of ML.

- o Focus on device
- o Focus on learning outside classroom
- o Focus on mobility of the learner

Pachler and others (Pachler, Bachmair, Cook, & Kress, 2010) discuss these phases in details, here we only provide a brief overview from their discussion. An obvious starting point to begin the discussion about the history of ML is mid 1990s when the general public started to widely use mobile devices for their day-to-day businesses. Several different projects focusing on the affordance of mobile devices sprang up to experiment with the idea of ML from a technological point of view. During this phase different ideas to demonstrate ML made productive use of e-books, classroom response systems, data logging devices and handheld computers in classrooms (Pachler et al., 2010). Re-usable Leaning Objects (RLOs) were proposed to be used on cell phones for learning. Limitation and strengths of mobile devices for use in ML were also highlighted.

The second phase of ML focused on the learning activities outside the classroom. Activities such as visit to museum and field trip were used to elaborate the implication of ML. Different pilot projects were started to underline the pedagogical aspects of ML.

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[1] http://www.xerox.com/
[2] http://www.hp.com/
[3] http://www.lexicon.com/

Examples of different projects initiated during the second phase in the history of ML include but not limited to, MobiLearn (MOBIlearn Consortium, 2002), HandLeR (Sharples et al., 2002) and Icamp (Sharma & Fiedler, 2007). All of these projects underlined that it is not the device but the learner who is mobile. These and similar other projects emphasized the need of new theories (i.e. ML theories) of learning which can take into account the radically different nature of ML.

The third and current phase of ML has broadened the borders of ML from formal (semi-formal) form of learning to include completely informal and lifelong forms of ML. The FABULA project is also an example of the third phase of ML. Three main foci of the projects during this phase are mixing ML with virtual reality, context sensitivity and ambient learning.

2.4. Characterizing Mobile Learning

The idea of using computing devices to help people learn is not completely new. From a conceptual standpoint ML can be considered as an extended subset of E-Learning, thus, it inherits the characteristics of E-Learning. Traxler (J. Traxler, 2005) outlines the main characteristics of ML as follows: ***Spontaneous, Private, Portable, Situated, Informal, Bite-sized, Lightweight,*** *and* ***Context-aware****.*

ML can arise from a need to accomplish day-to-day activities. ML is private to the learner, a learner may decide not to share with others the topics [s]he learns about for self-grooming or for self-sustenance. At the same time a learner may not be interested to learn the same topics as other learners. However, a learner may decide to share and discuss with other learners as [s]he learns. ML occurs on portable devices, usually handheld. It is situated in the contexts that are more than just *time* and *space* (Winters, 2006). ML changes the pattern of learning/work activities and is lightweight in terms of learning content and the amount of bytes flowing over the communication network. From a learner's point of view ML will enable them (Winters, 2006)

- o *To build knowledge in different contexts*
- o *To construct understanding*

Table 2: Difference between ML and E-learning (Laouris & Eteokleous, 2005)

e-learning	m-learning
Computer	Mobile
Bandwidth	GPRS, G3, Bluetooth
Multimedia	Objects
Interactive	Spontaneous
Hyperlinked	Connected
Collaborative	Networked
Media-rich	Lightweight
Distance learning	Situated learning
More formal	Informal
Simulated situation	Realistic situation
Hyperlearning	Constructivism, situationism, collaborative

When compared to E-Learning, ML is different. The main difference is the absence of mobility and formal nature of E-learning. Learning in the case of ML and E-learning is mediated through an electronic device, but in case of E-Learning it happens through the use of a full-blown computer that is usually stationary. E-Learning is also an alternative of traditional classroom based learning (D. Clark, 2007) and through its use universities like Oxford[1] and Harvard[2] offer online degrees and courses. ML on the other hand can both complement or conflict with formal education (Sharples et al., 2005), thus it can also conflict or complement E-learning, but cannot be an alternative to E-learning. The reason for this is mobility and flexibility attributed to ML. Table **2** provides key terminological differences between ML and E-Learning.

2.5. Advantages of Mobile Learning

ML has many advantages, first and foremost is its inherent flexible nature. A learner can carry his/her mobile device anywhere [s]he goes. Since a mobile device is always available (anytime, anywhere, just in time) to the learner, therefore the knowledge [s]he needs moves with him/her, as [s]he moves and is always present with the learner. Geddes (Geddes, 2004) proposes four fundamental benefits of ML

- o *Access*
- o *Context*
- o *Collaboration*
- o *Appeal*

ML allows the learners to access the learning content in the manner and time that suits their personal preferences. An added benefit is the cost of mobile devices which are used to access the learning content, such devices are less expensive compared to the cost of a normal computer. Benefits of mobile devices for learning are also noted by Kim and others (S. H. Kim, Mims, & Holmes, 2006) as they underline the independence of ML from location and time. They also discuss speed and freedom etc, from a technical point of view. During the process when ML occurs the learning activities of the learner can be used to provide the real time contextual information about the ongoing process of learning. Such contextual information can be used to improve the learning outcome of the activity. Since ML is more about the learner, therefore its learner centred approach helps to motivate the learners to get fully engaged in the learning process and to help other learners. Thus, ML supports collaboration and knowledge construction in real time.

The design of mobile technology appeals to the learner to use the device for learning. Jones and others (A. Jones, Issroff, E. Scanlon, G. Clough, & P. Mcandrew, 2006) elaborated on the appeal factor of ML and suggested six main reasons why learners would like to learn through mobile devices. Firstly, it is because ML would allow

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[1] http://www.ox.ac.uk/admissions/online_and_distance_courses/index.html
[2] http://www.extension.harvard.edu/

learners to pursue their own *learning goals*. Secondly, mobile device allows them to have more *control* over the learning process. Thirdly, affordance of mobile devices that allow them to *communicate* and collaborate with other learners. Fourthly, because using mobile devices is *fun* for them. The fifth reason they stated is the provision of context using mobile devices that allows them to locate resources and find information relevant to their learning context. Lastly, the mobile nature of device a allows them to divide the learning process into smaller chunks, thereby allowing them to learn continuously under different contexts. The interesting gadgets available in today's smart phones can therefore, act as a motivator to encourage potential learners to get engaged in learning activities.

2.6. Categories of Mobile Learning

The current state of ML literature can be used to place ML into four categories: *"technocentric, relationship to e-learning, augmenting formal education and learner-centred"* (Winters, 2006). Traxler and others (Kukulska-Hulme & J. Traxler, 2007; J. Traxler, 2007) have further extended and elaborated these categories to suggest the following different categories of ML

- o **Technology-driven mobile learning:** using technology specific breakthroughs for supporting learning
- o **Miniature but portable E-Learning:** relates to the adaptation of ML to already existing techniques of E-Learning
- o **Connected classroom learning:** using technology to support classroom learning
- o **Informal, personalized, situated mobile learning:** using technology to support ML outside the classroom under informal setting through the use of specific technologies
- o **Mobile training/performance support:** technology is use to increase the throughput of the workers who are mobile by providing information and support at the points when it is needed
- o **Remote/rural/development mobile learning:** using technologies to provide learning possibilities where traditional E-Learning support would fail

Categories of ML stated above provides an iterate-able list of different categories of ML. The application areas of ML are very vast and the term ML (i.e. Mobile Learning) is so general that any learning/work activity that happens through mobile device, when the position of the learner (also mobile device) is not fixed can be advocated to fall into a ML category stated above. As stated by Winters (Winters, 2006)*"[...] downside is that the unique nature of ML is becoming very difficult to characterize. Worst still, mobile learning, as a concept, is currently ill-defined; it seems to be all thing to all people"*. It is very likely that the application areas of ML will continue to grow and more categories of ML will appear. Furthermore, the idea of applying mobile devices for synchronizing work and learning activities has been exploited far more by industry than it has been debated in the research community. Therefore, in our view we need to filter what is important and put the less important aside. In other words we need to focus on very nature of the word ML "Mobility" and "Learning"; therefore, the focus should

be on the informal learning activities that occur in the state of mobility. This should therefore eliminate the other applications, which use mobile devices, but are not relevant for the field of ML.

2.7. Framing Mobile learning

From the above discussion it has already become clear that there are two fundamental aspects to consider about ML: namely "device aspect" and "learner aspect". However, there is a third aspect to consider that is the "social aspect" of ML. The social aspect is equally important as the other two, perhaps even more so when we consider that the eventual target audience of ML applications are users who care about their privacy, assign trust values to the other learning peers and expect the ML applications to observe ethical values.

To discuss ML from a holistic viewpoint Koole (L.Koole, 2006; 2009) suggests the "Framework for the Rational Analysis of Mobile Learning (FRAME)" which is capable to render all three aspects of ML while designing ML applications. Figure **4** depicts the FRAME model that considers *learner, device* and *social aspects* as the key features of ML. An important quality of the FRAME model is that it gives due importance to each aspect related to ML. The *device's aspect* considers physical, input, output, storage, processor speed, and error rate characteristics of the device that is to be used for the purpose of ML. From *learner's aspect* the important factors the FRAME model considers are prior knowledge, memory, discovery learning (i.e. learning style), and emotion/motivation while learning. Lastly from *social aspect's* viewpoint the FRAME model considers social interaction, conversation and cooperation among learners. Adaptation of the FRAME model can serve as an analytical tool for designing support for ML. Without providing an overview of social aspects concerning ML, which is beyond the scope of this chapter; the important point to underline here is the fact that the field of ML concerns three main aspects: they are the *mobile learner, mobile device,* and *social aspects*. While designing for ML systems all three aspects should be considered for successful implementation of ML.
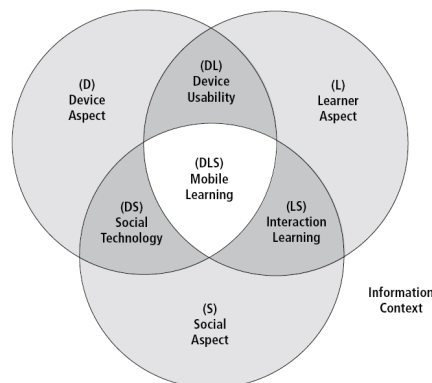
Figure 4: The FRAME model (L.Koole, 2006; 2009)

2.8. Citywide Mobile Learning

The definition of ML that occurs in cities is not very different from any other classic definitions of ML. However, the fundamental difference is the context (i.e. city) where the learning takes place. Since the learning activities are situated in the context of a city, they must also reflect upon different properties of the city, such as the different locations and other learners that are present in the city. Cities usually consist of noisy locations and they are full of people on the move, thus making them very dynamic in terms of movement of potential mobile learners. The noisy environment makes them an imperfect candidate to permit a formal form of learning activities in the busy streets bursting with people. Therefore, cities as a context for ML are more suited for informal ML, which does not require high level of attention or cognitive load, it instead encourages learners to engage into the learning activities. In the given scenario ML in cities may be defined as *"any informal learning activity that occurs through the use of a handheld mobile device which is carried by the learner whose position is not fixed relative to his/her physical surroundings and people (i.e. other potential learners) in the city"*.

2.8.1. What is Informal Learning?

The history of informal learning which considers it as social phenomena dates back to the 1970s (Tough, 1979). Informal learning can be defined as *any learning activity that occurs outside the formal learning environment and is not constrained by the time, space or predefined patterns of learning; it is motivated and controlled by the learner's goal of learning*. In order to avoid any misunderstanding it is important to underline the fact that formal and informal learning are mostly complementary and they rarely conflict, thus they can overlap. This is because under normal circumstances informal learning activities are either used to enhance already existing knowledge about a subject of interest or to gain completely new knowledge for immediate use.

> *In contrast to formal learning informal learning is not only faster and deeply rooted into all areas of life, it also caused to experiences and implicit knowledge. This knowledge is essential for social and technical complex assignments, which are more and more typical for our economy. That does not mean that we need no formal education furthermore. This mean, that formal and informal education are complementary sides of learning. Formal learning is the basis to understand complex coherences and informal learning is the basis for understanding and critical reflection of theory. That means formal learning is necessary to get the competences for effective informal learning and informal learning helps to bridge the gap between theory and practice. Only the combination of formal and informal leads finally to competence to act (Rohs, 2008).*

While reviewing at the literature that discusses informal learning, different views can be found and it seems that the concept of informal learning is ill defined. While providing an in-depth overview of informal learning Cullen and others (Cullen, Batterbury,

Foresti, Lyons, & Stern, 2000) suggest that *"there is not much to be gained in trying to squeeze informal learning into a definitional 'box'. This is especially true if the starting point for such an enterprise is to go for a mechanistic definition based on 'difference' between it and formal learning"*. However, for the purpose of this thesis, we will stick to the definition provided at the beginning of this section.

Colley and others (Colley, Hodkinson, & Malcolm, 2002; G. N. Vavoula, Sharples, E. Scanlon, Lonsdale, & A. Jones, 2005) provide an understanding of how to differentiate between formal and informal learning. In their view it is not trivial to define boundaries between formal and informal learning and such boundaries are meaningful only when they are drawn in relation to particular context, and for particular purpose. They suggest that examining the dimensions of formality, informality and their interrelation can be helpful to develop an understanding. Vavoula and Sharples (Giasemi N Vavoula & Sharples, 2008) also agree with this view and believe that characterizing a learning experience as formal or informal can be complicated.

Contrary to the view of Colley and colleagues is the view that suggests that any learning activity that takes place outside classroom settings can be regarded as informal learning. According to (Livingstone, 1999) *"informal learning includes anything we do outside of organized courses to gain significant knowledge, skill or understanding. [...] Informal learning is like an iceberg – mostly invisible on the surface and immense"*. Rohs also shares a similar view (Rohs, 2008) as he states *"term informal learning has its roots in the differences between of school and out of school education"*. Locus where the control of learning resides is another important aspect of informal learning and can serve as a distinctive factor to separate in/formal learning (Pickerden, 2004). From this standpoint formal learning is controlled by tutor and learner acts as a passive entity, while informal learning is completely under the control of the learner who acts as an autonomous learning entity. Similar to this view is Vavoula's (G. N. Vavoula, 2004) learning typology that mainly concerns the control over the learning process and *learning goal*. Figure **5** depicts the typology of learning. As it can be seen, informal learning can either be intentional or unintentional, while the formal form of learning is always intentional.
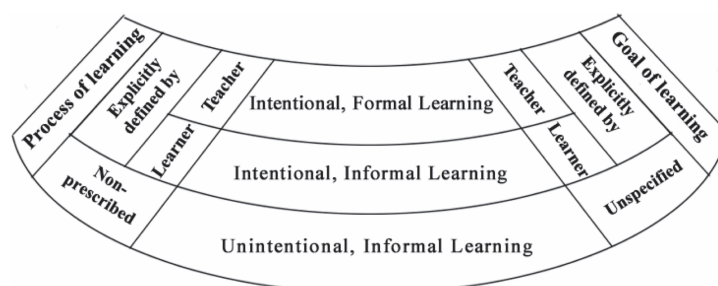
Figure 5: Typology of learning concerning control over process & goal of learning
(G. N. Vavoula, 2004)

Grebow (Grebow, 2005) focuses on the performance as the main reason for informal learning *"Virtually all real learning for performance is informal, and the people from whom we learn informally are usually present in real time"*. He describes different activities which result in informal learning *"informal knowledge transfer include instant messaging, a spontaneous meeting on the Internet, a phone call to someone who has information you need, a live one-time-only sales meeting introducing a new product, a chat-room in real time, a chance meeting by the water cooler, a scheduled Web-based meeting with a real-time agenda, a tech walking you through a repair process, or a meeting with your assigned mentor or manager."*

When digging deep into the literature of informal learning, many other approaches to define informal learning can be identified. However, the literature is patchy and pragmatic in focus, the theoretical foundations reflect tension and contradiction (Cullen et al., 2000). Instead of finding a universally accepted definition of informal learning, a better approach is to identify the important characteristics of informal learning. This will allow a better understanding of the distinctive characteristics of informal learning.

2.8.2. Characteristics of Informal Learning

Informal learning has some unique characteristics which differentiate it from other formal forms of learning. Hoffman and others provides the main characteristics of informal learning (Cullen et al., 2000; Hoffman, 2005; Rohs, 2008), in their view informal learning is:

- o **Just-in-time:** happens when the learner can put the knowledge or skills to immediate use
- o **Contextual:** it happens in all sorts of places such as office, city, home, pub etc.
- o **Individualized:** informal learning is triggered to meet a specific need
- o **Personal:** it takes place among the people who already know each other
- o **Chunked:** takes place as a result of events and usually dissolves in time quickly
- o **Limited in scope:** targeted to address a specific problem and can springs out as an *accident* while being engaged in daily activities, *intentional* as individual decides to learn something, *non-formal* in the sense that it is not planned or sponsored and *social* when learning happens as a result of advice from co-workers
- o **Happens outside school:** the context of learning is normally outside the boundaries of an institution
- o **Certification:** it does not earn a formal degree to the learner
- o **Intention:** the intention to take up such learning is not to gain knowledge, but to solve a problem
- o **Awareness:** most of the time informal learning is an unaware process
- o **Learning outcome:** result of informal learning is **Know-How** and understanding
- o **Control:** it is fully controlled by the learner
- o **Continues:** although informal learning happens in chunks, but the learning loop continues indefinitely

- o **Delivery mechanisms:** broad arrays of communication mediums are used for informal learning, now-a-days they are mostly electronic (e.g. mobile device, computer etc.)

2.8.3. Unifying Informal & Mobile Learning

From the discussion in the previous section it seems that ML and informal learning are the same concepts. To some extent this is partially true because ML has been mainly used in connection with informal learning. However, informal learning is a form of learning, which may or may not happen through mobile devices and from a conceptual point of view it is completely independent from ML.

Patten and colleagues (Patten, Sánchez, & Tangney, 2006) discuss different categories of applications utilizing capabilities of mobile devices to facilitate learning. In doing so they outline a functional framework that merges the functional aspects of devices with the pedagogical aspects. They suggest seven main categories of applications of mobile devices: **(1)** *A**dministrative:*** these applications mainly concern the group of applications use for managing the information related to education, such as calendar, schedulers and grading etc. *(2) Referential:* tools allow access to learning content while being mobile, this category may include ebooks, dictionary, translator etc. *(3) Interactive:* these applications require the user's engagement in the learning process through 'response feedback' loops. They help the user to memorize the learning concepts occupying his/her mind. *(4) Microworld:* scenario based applications allow learners to construct knowledge through experimentations. *(5) Data collection:* such applications allow the learners to collect data about their environment by using mobile devices. *(6) Location aware:* these applications use the position of the learner to construct the learning context of the mobile user, such applications encourage the learners to explore their environment. *(7) Collaborative:* these applications use the learner's mobile and context to encourage knowledge-building process among learners.

Constructing over the (Patten et al., 2006) categories of ML applications, Clough and others (G. Clough, A. Jones, P. Mcandrew, & E. Scanlon, 2008; Gill Clough, Ann Jones, Patrick Mcandrew, & Eileen Scanlon, 2009) conducted a survey to identify the different types of informal learning activities belonging to each category of Patten's (Patten et al., 2006) framework. Except for the *Microworld* they have identified several informal learning activities belonging to the remaining six categories of ML applications. Informal learning activities in the *Collaborative* category mainly occur when learners while using their mobile devices share data among themselves. This category consists of informal activities such as writing *Wikis*[1], writing *Blogs*[2], discussions using *WebForums*[3] and *"Beaming and Sharing"* activities which involve sharing data using peer-to-peer networking capabilities of mobile devices. Informal learning activities in the *Location Aware* category use geographical location of the

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[1] http://en.wikipedia.org/wiki/Wiki
[2] http://en.wikipedia.org/wiki/Blog
[3] http://en.wikipedia.org/wiki/Internet_forum

learner. Mainly relying on the Global Positioning System (GPS) to identify position of learner these activities encourage engagement of the learner into contextual learning activities such as *Downloading Contextual Information*. **Data Collection** category includes activities such as *Taking Audio Notes, Text Based Notes and Recording Images* using mobile devices. The **Administrative** informal learning activities include activities such as *Study Planning, Recording Performance, Using Calendar & Schedules and Storing Confidential Information* on the mobile device. **Referential** informal activities include the usage of *eBooks, Dictionaries, Treasures, Encyclopaedia, Course Material and Podcasts* on mobile devices. Finally the **Interactive** informal activities include *"Making Foreign Language 'flash cards'"* and using *Bespoke software*.

These different categories of informal ML activities highlight the variation in the type of informal ML activities undertaken by mobile learners. They also establish the relationship between ML and informal learning by identifying different types of informal ML activities. Based on categories just described it may be inferred that informal ML is a casual and unaware form of learning, the learner may not always be aware that [s]he is performing a learning activity using the mobile devices. Another point that seems to have been elucidated in this section is the blurred borders among *formal*, *informal*, *formal ML* and *informal ML*.

2.8.4. Characteristics of Citywide Mobile Learning

Based on the discussion provided in the previous sections, this section will draw attention to the conceptualization of ML in the citywide context. In the light of ML's discussion so far, this section will establish and identify the fundamental characteristics of CML. In general the characteristics identified here can be found in all CML activities, however in this section the discussion about each characteristic of CML is tailored to support vision the FABULA project.

Objective: An important question to answer when discussing CML is to define the *objective* of learning. This is to say that there shall be a general objective for learning activities; such an objective outlines the nature and mechanisms that shall be supported by the application designed to assist CML. This question is very crucial, and its answer must be articulated early during the design time. In the case of project FABULA we are interested to assist learners to learn about the city, while [s]he roams around in the city.

Goal & Intention Oriented: CML is goal and intention oriented in the sense that it allows learners to pursue their Learning-Goals based on their intentions and motivations for undertaking learning activities. It is important that there is a certain amount of flexibility in the choices available at the learner's disposal, so that they can decide what they want to learn about.

Informal & Contextualized: As discussed earlier [see section 2.8], city as a context naturally enforces informality in the leaning activities. Since learning occurs in the area of a city, it is important to take into account the physical structure of the city. Therefore, it is important to design the physical structures that will surround the learner

while learning. The exploration of physical structures of the city commences learning activities (Canova Calori, 2009). Similar approach has been suggested by (Kukulska-Hulme & J. Traxler, 2007) as they suggest to design physical learning spaces, in other words to design buildings for ML.

Individualized\Grouped: CML activities can be triggered by *interaction* and *serendipity* (Canova Calori, 2009; FABULA, 2007). This means that when a learner interacts with the other learners in the city, an informal activity involving many learners may be triggered as a result. Similarly, the solo learner may also engage in learning activities as [s]he explores the learning environment (i.e. city). In such a case when the learner is learning alone the application supporting CML shall assist and encourage the learner to engage in learning activities.

Learning Outcome: The learning outcome from CML activities is the "**Know-How**" and absorption of new concepts and ideas. In the case of the FABULA project this "Know-How" is better understanding about the prevailing environment (i.e. history, culture, social, religion and interesting sights) in the city.

Control: It is the learner who controls the flow of learning activities in informal CML. The learner is also privileged to decide the Learning-Goal [s]he would like to pursue. [S]He may decide to pause, resume, start and stop the learning at anytime.

Continuous: The CML learning is continuous and occurs as a loop. When the learner wants to start the learning process the previous state of last learning activity provides an input for the start of a new activity and thus allows the learner to learn incrementally and continuously.

Lightweight Delivery Mechanisms: The delivery mechanisms for CML are always wireless, this is due to the fact that learners and mobile devices are not fixed and thus cannot make use of any fixed networking facility. The learning content should be lightweight in terms of attention it requires from the learner and the bytes that flow over wireless networks.

2.9. Technologies for Mobile Learning

Before concluding the discussion of ML it is important to shed light on the intrinsic qualities (i.e. hardware & software) of mobile devices that have provisioned the primitive existence of ML in the first place. As a matter of fact, the existing consumer market is bursting with extremely powerful mobile devices. Central characteristics of these devices which make them highly tuned to support different forms of ML, are their portability, low cost, energy efficiency, connectedness, rugged design, personal, attractiveness, delightful, support special needs and effectiveness (Cyger, 2010). The characteristics offered by these new devices allow them to satisfy the ambitions of ML and thus make them a perfect fit to support ML. Sharples (Sharples, 2000) provides a discussion that matches the main properties of ML with the features available in mobile

devices. As learning is becoming *individualised, learner centred, situated, collaborative, ubiquitous and lifelong* the mobile devices are becoming *personal, user centred, mobile, networked, ubiquitous and durable.*

Numerous vendors are manufacturing different types of mobile devices that may be used to support ML. However, it is not practical to provide an exhaustive list all the vendors and all the available mobile devices which can fit ML's bill of requirements. From a hardware point of view, the main features that influence the overall performance of a mobile device are its processing power, available random memory, storage capacity, available networking support, display size, weight, device size and other interesting gadgets. Except for the display size commonly available mobile devices (for example Apple's[1] iPhone, iPad and Samsung's[2] Galaxy Tab, Smart phones) are capable to run heavy weight processes. From the viewpoint of using commonly available mobile devices for ML, there are a number of options available in terms of wireless networking and identifying the geographical position of the learner.

While hardware provides the processing power, software is the soul of any hardware. All the commonly available mobile devices also have a pre-installed mobile operating system. As the hardware is sophisticated the software that operates it is also not simple. A major strength of available operating systems for mobile devices is their extensibility. It is possible for developers to create application software that can run within the runtime environment provided by the operating systems and can access the hardware functionality of mobile devices. Two popular operating systems for mobile devices are Apple's iOS[3](Ali, 2010) and Google's Android (Google Inc, 2010; Murphy, 2009). Software Development Kits (SDK) are available for each of these operating systems. Both iOS and Android can be used for deploying ML applications.

2.10. Summary

If we now take a holistic view of the ML, it is easy to realize that ML introduces a completely new mode of learning. Arrival of more and more advanced and sophisticated mobile devices will fuel the evolution of ML. In such an environment the idea of ML seems to be very promising for the future. However, at the current state there is no clear focal point, instead it is spread in many different directions. The reasons for this situation are rooted in the distributed and large application areas of ML. However, the three main threads can be found in the current state of the ML. They are mobility of learner, mobility of device, and the social aspects. An important form of ML is informal ML, which perhaps is the most used form of ML. Since ML happens through mobile devices, this situation opens a window of opportunities for mobile devices to assist the learner as they use them for learning. Therefore, there is a need to design applications and platforms, which can make full use of the opportunities presented by the concept of ML.

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[1] http://www.apple.com/
[2] http://www.samsung.com/
[3] http://www.apple.com/ios/

Chapter 3

Overview of Learning Frameworks

"A framework is a real or conceptual structure intended to serve as a support or guide for the building of something that expands the structure into something useful. [...] (It) is often a layered structure indicating what kind of programs can or should be built and how they would interrelate" *(Whatis, 2008)*

This chapter will provide an overview of the platforms for technology-supported learning that happens through the use of digital devices and information technology. In relation to this thesis, the learning platforms discussed in this chapter provide an understanding of different approaches and techniques that are employed to support the learning activities. The **Main aim** — of this chapter is to ***justify the design approach adopted by FFC-ML*** presented in chapter 5.

3.1. Introduction

The ubiquitous availability of digital devices and free access to different wireless networks while being mobile has opened new possibilities for individuals to learn from each other. The teacher who was once the central entity to fulfil the learner's needs may not always be available in such form of learning. However, the availability of communications infrastructure alone is not enough to support ML. Picture of ML articulated in the last chapter points towards the need of well-designed information technology (IT) solutions to support ML. Consequently, technological facilities must be provided for knowledge sharing and construction. As more and more information becomes available "*we urgently need techniques to help us make sense of all this, to find what we need to know and filter out the rest; to extract and summarize what is important*" (J. Davies, Studer, & Warren, 2006). A system designed to support ML, will provide the supporting services *(functional units)* and mechanisms *(intelligent decision making)* to conduct learning and collaborative activities. Furthermore, it needs to be adaptive to altered modalities of learning.

A modular approach that exploits software services as the main building block of *learning support system*[1] will result in a superior system design, than other approaches

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[1] I will deliberately avoid the term "ML support system", as I establish an important understanding in section 3.3. Based on understanding established in section 3.3; in the scope of this thesis the term "Learning support system" stands for "ML support system".

which result in a single tone monothallic system design. Thus, service-based approach towards system design can result in interoperability (both syntactic and semantic), open, extensible and cooperative system (Blinco, Mason, McLean, & Wilson, 2004; Wilson, 2005) where each service is intended to fulfil a specific Learning-Task. Adopting a service oriented approach for system design may also be motivated by the fact, that a simple inspection of existing learning support systems unveils, that much of the functionality is replicated among different systems. Sometimes even the data is replicated among several systems.

3.2. Why We Need A Framework

By definition *"A framework creates a broad vocabulary that is used to model recurring concepts and integration environments and is equivalent to the concept of a pattern in the software community" (Wilson, Blinco, & Rehak, 2004)*. Different terms such as Frameworks, Platforms, and Architectures etc… have been used to refer to the concept of *"Framework"* described in this section.

The main purpose to adopt such an approach is to take a broad and general view of the learning system as a whole. Adoption of a framework would allow reducing the complexity of the system, by considering more general schemas/patterns that can be identified in the system. These schemas may consist of categories of services and functionality layers that exist in the system. Adopting such an approach would allow the system designers to pay due attention to particular aspects of learning supported by the system through its functionality. Such flexibility not only complements the technical aspects of a learning system, but also has a direct influence on the pedagogical features of the system (Wilson et al., 2004). A system that is built in a modular fashion can adapt very easily to integrate new modules (i.e. modules supporting both technical and pedagogical aspects of the learning). Flexibility in the core system design also allows evaluating different pedagogical aspects of a learning system.

3.3. Relationship Between ML & E-Learning Framework[1]

When articulated only in terms of **technology**, E-Learning is the superset of ML, in other words the learning achieved through the support of ML system, can also be achieved though E-Learning support system. The major difference is the support for mobility (of device and learner), which is absent in one while present in the other. In this sense ML is a sub-class of E-Learning, which is specialized based upon its contemplation for mobility.

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[1] The similarity relation established between E-Learning and ML during this section, stands only on the technological bases. The reader shall not mix it up with other varying dimensions of E-Learning and ML.

Positioning the argument on technological similarity between ML and E-Learning, we believe that many of the services needed to support E-Learning are also relevant for ML. Thus, the frameworks that have been designed to inform the design of E-Learning support systems can also be adopted to inform the design of a ML support system. While, the major deficiency of E-Learning frameworks is their limited or no consideration for mobility, extending and adapting the E-Learning frameworks for ML can eliminate this limitation. Since the field of E-Learning is far more mature than the field of ML. The technical design of E-Learning systems can offer a valuable input for ML, which in our understanding should not be neglected or overlooked. Based on this argument, we will use the term "Learning Framework" to stand for both "ML Framework" and "E-Learning Framework" for the rest of this chapter.

3.4. Frameworks for Technology Supported Learning

Constructing on the argument presented in the previous section, this section will provide an account of different learning frameworks. Several such frameworks have been proposed in the literature, which provide guidelines for designing learning support systems.

3.4.1. IMS Abstract Framework (IAF)

IP Multimedia Subsystem (IMS[1]) is a non-profit initiative of national learning infrastructure started in 1997. The formal name for IMS is IMS Global Learning Consortium, Inc. (IMS/GLC). Its aim is to develop web-service based specifications that can be utilized by any learning support system. The major highlight of IMS is the abstract framework (IAF), it is a device which enables IMS to describe the context within which it develops its E-Learning technology interoperability specifications (Smythe, 2003). Besides IAF, other important specifications produced by IMS are specification for Accessibility, Content Packaging, Digital Repositories, ePortfolio, Learner Information, Meta-data, Vocabulary Definition Exchange, Resource Description Framework (RDF) (Manola & E. Miller, 2004) Bindings, and Vocabularies. All these specifications revolve around IAF.

The core aspects of IAF (Smythe, 2003) are Interoperability, Service-orientedness, Component-based design, Layering and Binding neutrality (XML, WSDL, Java, etc). IAF acts as a device that enables IMS to describe the context within which it develops interoperability specifications of its E-Learning technology. IAF considers different perspectives and proposes views / architectures / models of a learning support system. The idea is to identify different components of an E-Learning system by examining it from different angles.

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[1] http://www.imsglobal.org/

IAF-Logical Perspective: is a collection of six layers; each layer uses the functionalities provided by the layer underneath it. This logical ordering identifies and provides information about all the main entities/components that a learning support system is likely to have.

IAF-Physical Perspective: separates the various components related to the actual deployment of the system. This view deals with the communication infrastructure and service categories. Service delivery engines, delivery devices and federated digital repositories are the other main components in this perspective.

IAF-Functional Perspective: is divided into two different perspectives, the content perspective and the individual perspective. The content perspective deals with the issues related to the content that is available for learning; these include the repositories, learner's profile management and catalogs. The individual perspective deals with issues related to the management of information about the learner.

Layers of IAF: As described earlier the IAF is a layered model; each layer provides support to the layer above it. The four general layers are as follows:

- o *Application layer:* consists of tools, agents and the applications needed by the user. It is the interface layer of the system and it abstracts the system's functional details from the user.
- o *Application services layer:* consist of the services that constitute of applications that support the actual learning. Services available in this layer support the learning activities. Collection of these services can be combined to build systems such as "learning content management systems", "content authoring tools", "Library management system"(Smythe, 2003).
- o *Common services layer:* provide services which act under the application services layer, they exists as the supporting services for services above them for smooth execution of the system's activities. These services can be considered as general purpose services such as calendar, collaboration, commerce etc.
- o *Infrastructure layer:* is the layer responsible for providing communication support to other services.

All the services are abstracted from one another and are only exposed through their service access points (SAP). A service may support more then one SAP(s).

3.4.2. JISC E-learning Framework and E-Framework

The E-learning framework and E-Framework are the initiatives by the U.K.'s Joint Information Systems Committee (JISC) to produce an evolving and sustainable, open standards based, service oriented technical framework to support education and research communities (Easterby, 2008). It is expected that E-Learning framework will be refractored and will become part of another initiative called E-Framework. The main difference between these two initiatives is that the E-Framework initiative focuses on developing a conceptual model of E-systems (E-Learning, E-Research, E-Admin, etc…)

where as E-Learning framework is intended to elaborate E-Framework for the purpose of E-Learning (i.e. to identify common services) only.

"*The main set of guideline principles of E-framework are service oriented approach to system and process integration, development promotion and adoption of open standards (such as IMS, OASIS, W3C, IEEE), community involvement in development of the e-framework and open collaborative development*" (JISC, 2006). Such a framework is intended to act as a design pattern for the service-oriented systems. It is not the focus of E-Framework to dive deep into the technical details. Instead, the aim of the framework is to identify services necessary for an E-Learning system and to be able to refer to one or more open specifications or standards that can be used for the implementation of those services. The structural part of E-Framework consists of reference models and services. A reference model is a placeholder for the concept of developing common learning, teaching, research or business requirements and show how services can be used to meet these needs. Where as the service exposes the information or functionality through a public interface that can be used to utilize that functionality (Olivier, Roberts, & Blinco, 2005). The identified services are sub-divided into domain specific services and common services. This approach is similar to the approach adopted by IMS abstract framework.

3.4.3. LSAL E-learning Services Architecture

The Learning Systems Architecture Lab (LSAL) conducts research focused on the design and creation of Internet-based technologies for education and training. LSAL came up with an E-Learning system stack called E-Learning Services Architecture (LSAL, 2001). The whole system is basically divided into three main layers, namely User Agent layer, Learning Services layer and Infrastructure layer.

- o **User Agent layer**: acts as an interface between the users and the system. User agent interacts with the *Learning Service Layer* and deals with the issues of delivering learning content to the user. User agents are built using the collection of services provided by the *Learning Service Layer*.
- o **Learning Service Layer:** is further sub divided into three different layers; namely *Tool Layer, Common Application Layer and Basic Services Layer*. Tool Layer consists of services that are used by the *User Agent Layer*. These services include content delivery services, tutors, simulators etc... *Common Application Services* include the services for content selection, sequencing, learner's profiling, report generation, knowledge management etc... *Basic Services Layer* includes the core learning services that are used by the *Common Application Services* such as right management, authentication, validations, logging etc.
- o **Infrastructure Layer:** deals with issues related to the communication channel used for delivering the learning contents. It addresses the issues such as the selection of appropriate transport protocol and the enabling services required to realize the physical communication in an E-Learning system.

3.4.4. Sun's E-Learning Framework

Sun's E-Learning framework (ELF) is broken down into four tiers each performing a critical function with in an E-learning system (Sun, 2003). *Presentation Tier, Common Service Tier, E-learning Service Tier* and *Resource Tier* are the names of different tiers of SUN-ELF. Figure **6** presents Sun's E-Learning Framework.
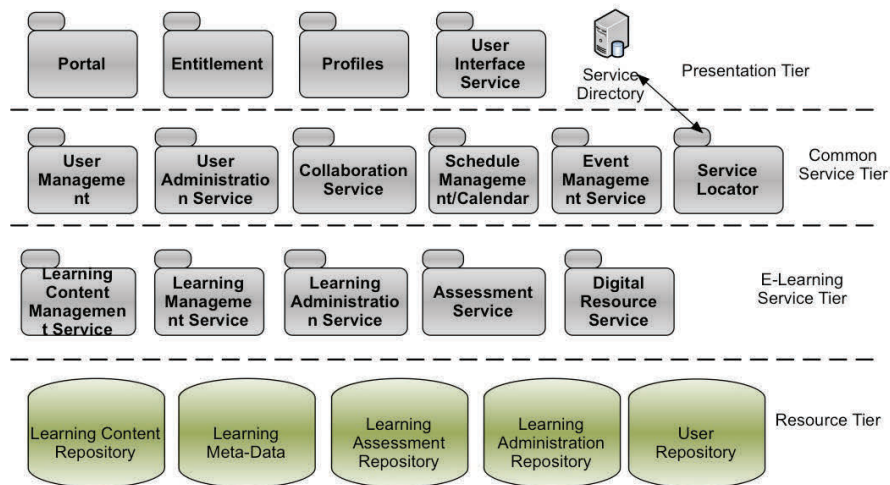
Figure 6: Sun's E-Learning Framework (Sun, 2003)

The major advantage of Sun's framework is its component-based approach for faster development, reduced development cost, and security. Presentation Tier: consists of navigation and presentation logic; Common Service Tier: constitutes the services which are common among the learning application; E-learning Service Tier: consists of components that support the non-learning, delivery-related administration functions, and Resource Tier: is based in the assessment system that measures student performance against specific learning goals.

3.4.5. LTSA-IEEE Reference Model

The Learning Technology System Architecture (LTSA) IEEE reference model provides specification for the systems and components for technology supported learning (Farance & Tonkel, 1998). Figure **7** presents the layers of this architecture. The proposed standard does not focus on the type of technology used for its implementation; furthermore it is also content, pedagogical, and cultural neutral. This conceptual framework:

o   Provides guidelines for understanding learning systems

- o Underlines the critical interfaces of the systems, thereby allowing for efficient implementation of the system because the common components and interfaces are only implemented once
- o Adapts to technology changes because the adaptation is only an incremental change when viewed at the right level of abstraction, i.e. helping to manage change and reduce technical risk

Figure 7: LTSA abstraction-implementation layers (Farance & Tonkel, 1998)

3.4.6. Open Knowledge Initiative (OKI) Architecture

The Open Knowledge Initiative (OKI) also provides a service-based architecture; the main focus is on formal forms of learning, e.g. quizzing, authoring and administration (Kumar, Merriman, & Thorne, 2002). "O.K.I.-based systems should be able to handle the demands of institutions with potentially thousands of faculty, thousands of courses, hundreds of thousands of students, multiple campuses, and students accessing courses from remote locations". Therefore, it is specifically designed to meet the needs of higher education. The target applications of OKI include amongst others the academic systems, library information systems, central administrative systems, student information systems and digital repositories. It provides application programming interfaces (APIs) to allow the integration of new technologies into the OKI-based systems. A number of APIs have been released by OKI, which are publicly available. It follows standards to promote interoperability among learning systems. Figure **8** presents the four different layers of the OKI architecture.
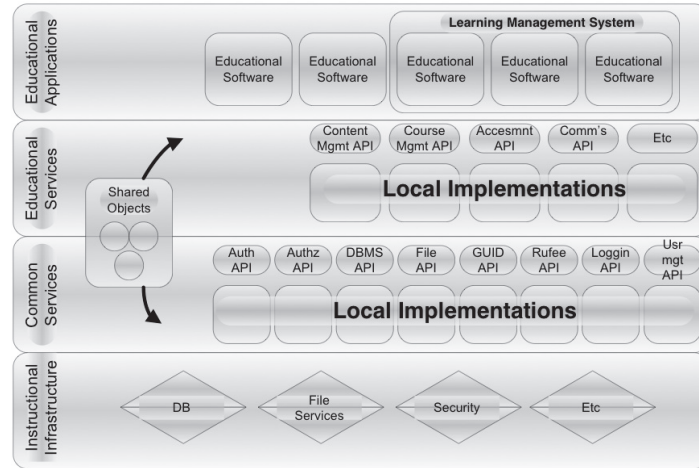
Figure 8: OKI architecture for learning management systems (Kumar et al., 2002)

3.4.7. OMAF Layered Model

MOBIlearn (OMAF) is a layered abstract model that has been designed and implemented as a service-oriented architecture (Bormida, Girolamo, Dahn, & Murelli, 2004). This framework focuses on the interfaces between the learning system layers. It considers explicitly the mobility of the learner. The underlying principle is to follow a user centred design and proposes the conceptual layout of the services to access the learning resources. The MOBIlearn project implements this framework. Figure **9** depicts the layers of OMAF.
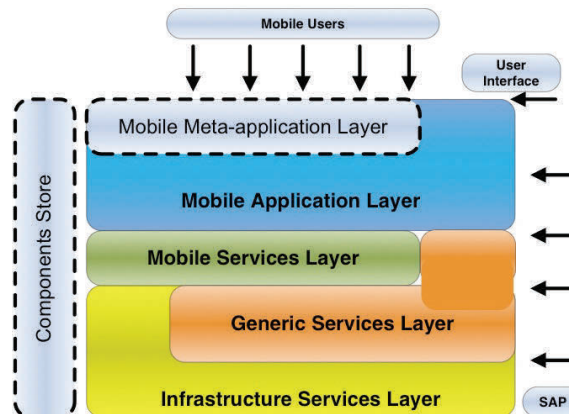
Figure 9: The OMAF layered model (Bormida et al., 2004)

o **Mobile Meta-Applications Layer:** consists of applications and tools which are constructed from two or more mobile applications to support more complicated and extended functionality. Mobile Applications Layer: are the applications which are designed and implemented to provide mobile functionality

- o **Mobile Services Layer:** these components provide mobile services to the mobile application layer
- o **Generic Services Layer:** as the name suggest these components provide generic services
- o **Infrastructure Services Layer:** these provide communication, messaging and transaction support Service Access Points: these are implemented as interfaces in APIs. Each interface provides access to one service capability
- o **Components Store:** provides components to support generic mobile services

3.5. Common Aspects of Existing Frameworks

Common aspects that are identified after comparing the frameworks discussed in the previous section are:

- o Services are always layered over each other; the services in the lower layer provide support to the services above them.
- o A digital repository is used to manage (store) the learning contents within the system
- o Application services are fine grained services which the user directly interacts with such as quizzes, simulations, etc.
- o Educational services usually revolve around education administration such as course management, scheduling, etc.
- o Common services provide the functionality that the user is not directly exposed to, but is essential, such as authentication, file sharing, logging, database management, etc.
- o The infrastructure consists of the backbone services dealing with HTTP, SOAP, XML, etc.

3.6. Strengths and Limitations of Existing Frameworks

Measuring the strengths or limitations of a framework is not a trivial task. However, based on the area of application, different parameters for evaluation can be identified which influence the adaptation of a framework in a particular application context. For the purpose of this thesis, the evaluation parameters are identified in the light of CML as the main application area.

The following evaluation parameters are identified:

- o **Abstract:** An abstract framework is good, however the shortcoming is that it is too general and the scope of application becomes very wide. By abstract we mean a framework that only provides guidelines, but does not provide a concrete implementation of its own
- o **Follows standards:** A Framework which follows standards is better than the one that does not follow standards

- **Service oriented:** A services based framework is better than one which is locked into a single functional unit
- **Involves agents:** involving software agents in the framework allows a software system to participate actively in the learning processes
- **Considers informal learning:** most of the frameworks consider learning to be a formal activity, such as classroom learning. However, in our work we are more interested in informal learning
- **Contextual aspects of learning:** aspects such as the nature of the learning activity, time and the Space/Place where the learning happens, greatly affect the learning process when we consider learning in a citywide context
- **Situatedness support:** certain learning activities can only occur when the learner is situated in a particular environment and is surrounded by a certain set of conditions (e.g. other learners, learning resources, vicinity of historical buildings etc.) A learning framework that considers the aspects of situated learning and provides for its support has advantages over one that does not
- **Concrete services description:** just informing about the names of the services is not enough, a framework should also suggest the finer details of the learning services; such as the input/out, contextual use of services, pre/post conditions etc.
- **Collaboration support:** while considering mobility of learner in a wide contextual space. Along with the learning services there is also a great need for services to support collaboration between learners. Collaboration support includes things such as taking a combined decision, group discussions, creating an artefact together (document, drawing etc.).
- **Interoperable:** a framework should consider interoperability with other systems
- **Extensible:** a learning framework should allow the extensibility of a learning system. In this regard it should be possible to extend the system with new learning applications. In this way system should be able to support different forms of learning

Table 3: Comparison of existing frameworks

	IAF	LSAL	SUN's E-learning	LTSA	OKI	OMAF
Abstract	Y	Y	N	Y	N	N
Follow standards	Y	N	N	Y	Y	Y
Service oriented	Y	Y	Y	N	Y	Y
Involves agent	P	P	N	Y	N	N
Considers informal learning	N	N	N	N	N	Y
Contextual aspects of learning	P	P	N	Y	N	Y
Situatedness support	P	N	N	P	N	P
Concrete services description	N	N	N	N	Y	Y
Collaboration support	P	Y	Y	P	Y	?
Interoperability	Y	P	Y	P	Y	?
Extensible	Y	P	Y	Y	Y	Y

Legends Y = Yes, N = No, P = Partially

Table **3** provides an analysis of the strengths and limitations of frameworks discussed in the previous sections against our chosen parameter. Form the analysis it is evident that all the frameworks discussed here lack some support needed for CML. The discrepancy in these frameworks is because CML was not their primary goal at the design time. In the given situation, it is necessary to construct a framework that considered CML as its main target application and reflects its support for CML in its services and system components.

3.7. Summary

A recap of the discussion provided in this chapter suggests that the technological frameworks designed to support learning, be it ML or E-Learning can provide a valuable insight for a framework to support CML. The layered approach to organize system's functionality, identified services to support learning and system components can be adapted or extended to support CML. Thus, existing frameworks can be used to develop a rough sketch of a new framework for CML. However, not everything can be adapted, a framework to support CML should take a reductive or eliminative approach when dealing with the aspects of formal learning which are predominantly prevailing in existing learning support frameworks. Other important differences which a CML framework will have, is its intensive consideration to support learner's mobility and informal formal form of learning.

Chapter 4

Software Agents and Ontologies

"...need for some degree of autonomy, to enable components to respond dynamically to changing circumstances while trying to achieve over-arching objectives, is seen by many as fundamental. Many observers therefore believe that agents represent the most important new paradigm for software development since object orientation" (Luck, McBurney, Shehory, & Willmott, 2005).

"An ontology is a computational model of some portion of the world, it is often captured in some form of a semantic network (such as Definitional networks, Assertional networks, Implicational networks, Executable networks, Learning networks, Hybrid networks) - a graph whose nodes are concepts or individual objects and whose arcs represent relationships or associations among the concepts. The network is augmented by properties and attributes, constraints, functions, and rules, which govern the behaviour of the concepts"(M. P. Singh & Huhns, 2005).

This chapter will provide a background understanding of two closely related domains of computer science that are relevant to the work presented in this thesis. Namely, it will discuss the notion of software agent and ontology in the context of CML. For the purpose of providing automated support in the highly dynamic environment where CML occurs, we have extensively use software agent as a metaphor to model and support dynamic system behaviours. The domain knowledge which employs the notion of *Place/Space* to render the city into an arena of learning, is formalized in the form of an ontology. Commitment to the formal semantics of this ontology, allow software agents to communicate, coordinate and negotiate to offer automated support for CML. **Main aim**—of this chapter is to ***construct background understanding of software agent and ontology*** as two important concepts applied in this thesis to support CML.

4.1. Software Agent

The term agent has emerged from the field of Artificial Intelligence (AI), however it has been adopted in so many different domains that there is no generally accepted definition of the term software agent. Nwana (Nwana, 1996) describes it as an umbrella term, meta-term or a class and suggests a topology that divides software agents into seven broad categories, namely *Collaborative agents, Interface agents, Mobile agents, Information/Internet agents, Reactive agents, Hybrid agents and Smart Agents*. Without going any further into the details of types and categories, a software agent can be understood as *a computational surrogate for an active real world entity that has the*

capability of performing autonomous actions on its environment to achieve its goals. The application area determines the complexity of a software agent. Consequently, the perceived understanding of the term is different in dissimilar application domains. Software agents have been applied in different domains, a few of them are Peer-to-Peer systems (Moro, Ouksel, & Sartori, 2003), Grid Computing (Olejnik, Toursel, Ganzha, & Paprzycki, 2007) and E-commerce (Maamar, Yahyaoui, Mansoor, & Heuvel, 2001).

Wooldridge and colleague (M. Wooldridge & N. R. Jennings, 1995) suggest four main properties of a software agent. **Autonomy:** this property of agents suggests that they perform their actions without external intervention. **Social Ability:** means that agents communicate with each other through the use of a communication language. **Reactivity:** nature of agents suggests that they perceive their environment and respond to the changes that occur in it. **Pro-Activeness:** agents perform actions in order to accomplish some goals. Wooldridge and colleague (Michael Wooldridge & Nicholas R Jennings, 1995) highlight three key issues involved in software agents. According to them, **Agent theories:** describes the different properties we associate with software agents to understand and reason about it**. Agent architectures:** are the approaches we use to construct the agents that satisfy the properties described in agent theory**. Agent languages:** relate to the adopted language to programme and execute the agents.

Russell and colleague (Russell & Norvig, 2002) discuss main characteristics of software agents. In their view a software **agent always exists in some kind of environment**. It can perceive its environment and can act accordingly. The environment can be fully or partially observable and the outcome of performing action in the environment can either be deterministic or non-deterministic. The states of its environment can be static or dynamic and can either be discrete (i.e. finite) or continuous (i.e. infinite). Environment may consist of one or more agents. **Agent Communicates and Negotiates with other agents**. Negotiation can be defined as "*The process of several agents searching for an agreement*" (Oliveira & Rocha, 2001), two main mechanisms for agent negotiation are *voting* and *auctions* - "contract net protocol" (and it's variants) is an established protocol for agent negotiation. **Agents Plan and Coordinate their activities**, during the process of planning an agent selects certain tasks to be processed at certain time points, these tasks can be conflicting in their nature. An agent may need to find certain resources to perform tasks, it may also need to resolve conflicts among the task and choose the optimal solution. During this process it may use the expertise of other agents or provide its own expertise in order to perform a task and thus coordinate with other agents. **Agent's Internal Architectures may vary**, based on the sensory input, agent selects an action to be performed against the input and this input is called *percept*. The function that maps the input to agent action is called Agent Function, Agent Behaviour or Agent Architecture. Below are a few types of Agent Functions:

Model Based Reflex Agent: is very simple and has a direct one-to-one mapping between the percept and the action

Model Based Agent: keeps a model of its environment inside it, like a small database. Every time a new percept arrives the agent function maps this percept to an action based on the percept and the state of the model of its environment.

Under such settings an agent size can be increased significantly. This is to say that a certain number of previous precepts is kept inside agent for future use

Goal based Agent: Knowing the state of environment is not always enough. There is also a need to know about the desired goal state. All the actions of an agent are then oriented to achieve the goal state. Search and planning could also be the part of agent function in this case. This type of agent can also do reasoning based on the internal representation of the environment in order to take actions. Overall agent execution is much slower than the reflex agent, however such agents are highly flexible as the knowledge that supports their decisions in represented explicitly and can be modified. Such agents can effectively adapt to the new situations and their behaviours act with high synchronization.

Utility Agent: assigns utilities to its actions and then executes the actions having the highest utility against a percept. In a certain situation there can be more than one action that an agent can perform in response to a percept. These agents can be considered as the extension of goal based agents.

Learning Agent: Agents which use such a model have special capabilities embedded in them, this means that such agents can learn new knowledge. Such agents can operate in a completely new environment, with an ability to adapt to new conditions. Actions of these agents against a percept are based on the collective (new and old) knowledge they acquire during their learning.

Another way to explain software agent is to consider it as a design metaphor that provides "*a way of structuring an application around autonomous, communicative components, and lead to the construction of software tools and infrastructure*" thereby providing a "*more appropriate route to the development of complex computational systems, especially in open and dynamic environments*" (Luck et al., 2005). In this case it is important to identify *agency (i.e. points where agent support is needed)* in the application domain.

4.1.1. Agent Communication

As discussed earlier, agents communicate with each other, the approaches for agent communication are inspired by the speech act theory (Austin, 1975; Searle, 2003). In simple words speech act can be described as *in saying something we do something*, such as declaring, describing, asking, requesting or committing[1]. The agent usually communicates by message passing, two popular agent communication languages (i.e. content languages) based on *predicate logic*[2] are *Knowledge Query and Manipulation Language* (KQML) (Finin, Fritzson, McKay, & McEntire, 1994) and Foundation of Intelligent Physical Agents (FIPA)-SL (FIPA-SL, 2002). In these languages the domain entities are described using *terms*, and are used to construct *facts (i.e. sentences, statements*) describing the state of the domain. Compound facts are formed by combining simple facts using operators (e.g. *and, or, not etc.)* and quantifiers (e.g. *for*

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[1] http://en.wikipedia.org/wiki/Speech_act
[2] http://en.wikipedia.org/wiki/Predicate_logic

all, there exists, etc.). "*Content language defines some 'built-in' constants, functions and predicates, and any others used in any given content expression are assumed to be defined in an ontology*" (Cranefield & Purvis, 2003). KQML as an agent communication language provides a set of *performatives* which can be used by the agents, it also introduces the concept of *communication facilitator.* The communication facilitator provides different service to the agents who communicate with each other. Agent Communication Language (ACL) (FIPA-ACL, 2002) provides a very comprehensive mechanism for agent communication, the message format of ACL allows associating meta-data information to the content of the message. It also provides a set of *preformatives* with predefined semantics. The standard specification recommends use of FIPA-SL (FIPA-SL, 2002) as the content language of ACL messages.

4.1.2. Multi-Agent Frameworks

A Multi-Agent System (MAS) is defined as "*a loosely coupled network of problem solvers* (i.e. agents) *that interact to solve problems that are beyond the individual capabilities or knowledge of each problem solver*" (Durfee, Lesser, & Corkill, 1989). Going into the details of MAS is beyond the scope of this thesis; Sycara (Sycara, 1998) discusses MAS in great details. A straightforward approach to design a MAS based system is to go though all the phases of system analysis and design. Thus, every time a MAS needs to be built; the process has to be started from scratch. However, there have been a number of attempts in the research community to propose generic Multi-Agent frameworks, which can be applied and reused in a number of situations to construct different MAS's. Different Multi-Agent frameworks are available each targeting different application areas such as *power system automation* (Z. Yang et al., 2006), *decision making* (Sallard, 2009), *stock trading* (Yuan, Kecheng, & N. D. Davis, 2002), *building automatic operational profile* (Yaman, 2007), *home care* (Fraile, Bajo, Abraham, & Corchado, 2009), *context awareness* (Bürkle et al., 2007), *data mining* (P. Yang, Tao, L. Xu, & Z. Zhang, 2009) and others (Collins, Tsvetovat, Mobasher, & Gini, 1998; Decker & Sycara, 1997; N. R Jennings, 1994; Sycara, 1998). We do not intend to provide an exhaustive list of all the Multi-Agent frameworks, instead in the context of this thesis it is more important to highlight the main characteristics of a Multi-Agent framework.

o The main goal of a Multi-Agent framework is to provide a certain set of services to other agents and to design some generic system components which can provide these services
o The Multi-Agent framework may or may not follow a metaphor. However, the framework that follows a metaphor has an advantage over others as the conceptualization of entities becomes explicit
o Most of the frameworks enforce their own concepts to be adopted by the agents who want to use services provided by the frameworks. However, there is very limited support to extend the frameworks in order to provide more functionality. For instance, if the main goal of the frameworks is to provide access to heterogeneous

resources then it is not possible to adopt the frameworks for market based negotiation support.

4.1.2.1. AGORA Multi-Agent Framework

Important to this work is AGORA (Matskin et al., 2000; Niu et al., 2007; Petersen, Matskin, & Rao, 2008; Rao & Petersen, 2003; Su, Matskin, & Rao, 2003) that has been successfully applied for virtual enterprises, for e-commerce and CML. AGORA framework has evolved since it was first proposed in 1998. Different implementations of the framework exist each using its power to comprehensively capture the details of cooperative activities and mapping them into a MAS. The literal meaning for AGORA[1] is a *"place of assembly"*. People would gather in the AGORA for military duties or to hear statements. Later, the AGORA also served as a marketplace where merchants kept stalls or shops to sell their goods. Simply said, AGORA serves as a place where different interested parties get together to discuss their interests. The place provides different facilities to coordinate, negotiate and manage the activities.

4.1.3. Application of Software Agents in Mobile Learning

For obvious reasons software agents have been applied in ML for various purposes. Qualities which make them suitable for ML are their autonomous behaviour, strong connection with AI and ability to perform several useful operations concurrently. Another aspect of their suitability for ML is the very nature of ML which is dynamic and requires a lot of automated support from the technical solution intending to support it. In other words, software agents fulfil a large number of requirements prescribed in the ML's bill of requirements. These qualities along with others make them a perfect match for ML.

Researchers have used software agents differently to support ML. Following are some major application areas of software agents in ML. **Recommendation**: is a way of suggesting suitable information and/or resources to the user for a particular purpose. From the stand point of ML, the main goal of *recommendation* is to suggest the learning content to the learner that would most likely help him/her to learn. Examples of such systems benefiting from software agents for recommendations are presented in (Andronico et al., 2003; Drachsler, 2009). **Personal Assistant:** software agents can perform intelligent operations to support the user, these include but are not limited to downloading information for later review, offline processing, communicating or negotiating on behalf of its user etc. Carolis and colleagues (De Carolis, Pizzutilo, Cozzolongo, Drozda, & Muci, 2006) have used software agent (called MyCoach) as a proxy to represent its user, the software agent manage interactions on his/her behalf; (McGovern, Roche, Mangina, & Collier, 2007) and also present a similar approach. **For Language Learning:** computer-based training sessions have been used effectively to help people learn or improve their language skills. Chen and colleague (Chen & Hsu,

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[1] http://en.wikipedia.org/wiki/Agora

2008) suggest an agent-based system to help mobile learners to improve their English language skills. **For Tutoring:** Glavinic and others (Glavinic, Rosic, & Zelic, 2007) suggest a mobile tutoring system that is constructed through the application of software agents. In their view such a tutoring system is capable of *(1) Taking over the Role of a Human Teacher, (2) adapting the user interface to individual user's needs, (3) enabling cooperative learning, (4) enabling competition, (5) searching the information space, (6) help in using virtual reality systems, and (7) adjusting the system to the device used for accessing the system.* **Personalization:** is a way of meeting individual requirements, (Hur, H. Kim, & Ko, 2005) use agent based system for personalizing the English words learning, another similar example is (Esmahi & Badidi, 2004). Many other applications of software agents in ML can be identified in the literature, such as Lin (Lin, 2004) discusses how the application of special kind of agent (i.e. mobile agent) can improve the overall environment for ML. Udanor (Udanor, 2011) presents a software agent based approach to access learning objects from distributed learning repositories.

4.1.4. Multi-Agent Development Tools

A number of tools are available for creating MAS, each having special features. These tools provide API and some form of *Integrated Development Environment* (IDE) support to create and programme MAS. Both open source and commercial tools are available in the market. A comprehensive list containing more than 40 different tools is provided by (Braubac, 2011). Selecting a MAS development tool is specific to its application context, (Sánchez López, Brintrup, McFarlane, & Dwyer, 2010; Shakshuki & Jun, 2004) provide evaluation of such tools.

Following are a few commonly used agent based development tools, *Java Agent Development Environment* **(JADE)** (Bellifemine, Caire, & Greenwood, 2007), **JACK** (Howden, Rönnquist, Hodgson, & Lucas, 2001), *Agent Development Kit* **(ADK)** (H. Xu & Shatz, 2003), *Cognitive Agent Architecture (Cougaar)* (Gracanin, H. L. Singh, Hinchey, Eltoweissy, & Bohner, 2005), **Soar** (Sun, 2005), **Jason** (Boss, Jensen, & Villadsen, 2010), **Agent Factory** (O'Hare, 1996), **3APL** (Hindriks, De Boer, Van Der Hoek, & Ch. Meyer, 1999), **MadKit** (Gutknecht & Ferber, 2001), *SRI Procedural Agent Realization Kit* (**SPARK**) (Morley & Myers, 2004).

JADE stands out of the crowd as it is fully open source and is a widely used agent development tool. It was developed during 1998 and was made open source during 2000. The code base of JADE has evolved ever since it was made available to the general public, different add-ons can be created and merged with JADE. A huge number of such add-ons are available each attempting to make JADE useful for a particular purpose. It is fully compliant with FIPA standards. JADE also provides a comprehensive JAVA library to create software agents, debugging support is also available for eliminating logical bug in software agents.

A JADE platform consists of one or more number of *Containers*. The Container provides life cycle services to the agents. A *Container* can provide life cycle services to any number of agents. A special Container called Main-Container acts as a hub to which

all other Containers (non-main) connect to form an agent platform. It also provides the *Agent Management Service* (**AMS**) and *Directory Facilitator* (**DF**). A JADE platform can consist of Containers distributed over different networks and computers.

4.2. Ontologies

Ontology is a way to formally and explicitly represent knowledge dealing with some specific portion of the world. Several definitions of ontology have been proposed by different authors, for example Singh (M. P. Singh & Huhns, 2005) define it as *"a kind of knowledge representation describing a conceptualization of some domain. An ontology specifies a vocabulary including the key terms, their semantic interconnection and some rules of inference",* Gruber (Gruber, 1995) suggests that *"ontology is an explicit specification of a conceptualization. The term is borrowed from philosophy, where an Ontology is a systematic account of Existence",* Guarino (Guarino, 1998) *"An ontology is a logical theory accounting for the intended meaning of a formal vocabulary",* Genesereth (Genesereth & Nilsson, 1987) defines ontology as a formally represented knowledge conceptualized in the form of objects, concepts, other entities and their relationships. Among all the different definitions a common goal is to convert knowledge into a formal form (i.e. to represent it).

4.2.1. Why to Represent Knowledge?

An important question that arises is *"what do we achieve by representing knowledge"*? In other words *"why would we want to create ontology"*? Davis and others (R. Davis, Shrobe, & Szolovits, 1993) suggest five important reasons for which one would want to represent knowledge.

Firstly: represented form of knowledge acts as a ***surrogate*** (i.e. replacement, substitute, proxy) of the real. Since it is not possible to take the physical world into the intangible world of computer programmes, we need therefore to create a model of our world consisting of concepts, objects and relationships which exists in reality inside computers. Pointed out by the authors (R. Davis et al., 1993), is the fact that a surrogate can never be a complete representation of the reality. Gruber (Gruber, 1995) also elaborated on this important point in this way. Since an ontology (i.e. represented knowledge) is a specification of a focused part of the world (i.e. specific domain), commitment to a common ontology therefore does not guarantee completeness (from a global perspective), with respect to queries and assertions using the vocabulary defined in the ontology.

Secondly: by representing knowledge we create a ***set of ontological commitments.*** This is to say that, by representing particular aspects and ignoring others, we implicitly make ontological commitments. *"The commitments are in effect a strong pair of glasses that determine what we can see, bringing some part of the world into sharp focus, at the expense of blurring other parts" (R. Davis et al., 1993).* In agreement with this view, Guarino (Guarino, 1998) stated that *"its ontological commitment to a particular*

conceptualization of the world. The intended models of a logical language using such a vocabulary are constrained by its ontological commitment. An ontology indirectly reflects this commitment (and the underlying conceptualization) by approximating these intended models". Common ontological commitment is a way for software entities such as agents to share, understand, communicate, negotiate, coordinate and reason about their actions and environment(s).

Thirdly: representing knowledge provides ***fragmentary theory of intelligent reasoning.*** This is perhaps an obvious outcome, since such a representation is motivated to explicate real world intelligent reasoning. According to authors the theory is fragmented because of two reasons *(1) the representation typically incorporates only part of the insight or belief that motivated it, and (2) that insight or belief is in turn only a part of the complex and multi-faceted phenomenon of intelligent reasoning (R. Davis et al., 1993)*.

Fourthly: represented knowledge acts as a ***medium for efficient computation***. A formal representation of knowledge allows efficient reasoning. **Fifthly:** a represented form of knowledge is ***medium of human expression***. This is to say that knowledge representation allow humans to communicate with machines.

As stated earlier, ontologies are a way of representing knowledge. There may be different reasons why we would want to create an ontology, few of them are stated above. It is not necessary that while creating an ontology a designer will have all the reasons in mind. However, an important reason is to formally represent knowledge. The represented form of knowledge (i.e. ontology) allows software entities to have a common understanding of the domain where they are applied.

4.2.2.   Different Aspects of Ontologies

By using and creating ontologies, different benefits can be achieved. Uschold and colleagues (Uschold et al., 1999) suggest different benefits of ontologies. According to them ontologies allow ***Communication:*** among people. Another benefit of ontologies is ***Inter-Operability:*** among computer systems through translation by acting as an *interchange format*. Ontologies also provide several benefits to *Systems Engineers*, as they allow ***Re-Usability:*** of formally described *concepts, attributes, processes and their interrelationship*, ***Search***: by providing meta-data facilities in repositories, ***Reliability:*** the formal represented form of ontologies allow execution consistency checks resulting in more reliable software, ***Specification:*** by assisting in requirements identification and defining specifications, ***Maintenance***: support is provided by the ontologies in different ways, such as by providing improved documentation, and ***Knowledge Acquisition:*** use of existing ontologies speeds up the development process that results in guiding knowledge acquisition.

While designing ontology a few considerations should be taken into account, Singh (M. P. Singh & Huhns, 2005) emphasizes a few important issues. Creating ontology for a domain from scratch is a time consuming and tedious task. Therefore, some knowledge

discovery techniques should be employed to automatically create ontologies. As the knowledge about a domain evolves the ontology about the domain should also evolve if it is to stay useful any longer. Since there will be several ontologies about the same domain on a place like Internet, these ontologies will have several identical concepts consisting of different attributes, but same/related semantics. Therefore, there is a need to develop methods to construct consensus ontologies and to reason with ontologies even when they are in-consistent. Gruber (Gruber, 1995) suggests a few design criteria for creating ontologies, they are ***Clarity, Coherence, Extendibility, Minimal encoding bias, Minimal ontological commitment.***

Based on the level of generality adopted, ontologies can be divided into three different kinds. Guarino (Guarino, 1997) identify three different kinds of ontologies. ***Top-level ontologies:*** are the ontologies which describe very general concepts and are independent of any specific domain, ***Domain ontologies*** and ***task ontologies:*** describe vocabulary related to a generic domain or generic tasks and activities, they are more specialized than top-level ontologies***, and*** **Application ontologies:** particularly focus on a specific domain and describe its details. Ontologies may also perform different roles (Uschold et al., 1999) such as ***Operational Data Role, Ontology a role that information plays***, and ***Ontology Representation Language.***

4.2.3. Key Enabling Technologies

For creating ontologies different languages have been created. **Resource Description Framework (RDF)** is a language for representing information about the resources in the World Wide Web; with a particular intention to represent metadata about web resources (Manola & E. Miller, 2004; M. P. Singh & Huhns, 2005). RDF supports a mechanism of presenting knowledge in a graph like structure. It follows the notion of N-Triples, it assumes that things being described have *properties* which have values. All the statements/assertions made using RDF are presented using three main elements.

- o Subject
- o Predicate (*also called property*)
- o Object

Subject and *Predicate,* each is a *Resource*. A *Resource* is anything that is identified by a URI *References*. *Object* in an RDF statement could either be a *Resource* or a *Literal*. *Literal* could be a plain *string* with an optional associated *type*. In a graph format *Subject* and *Object* present nodes of the graph and the *Predicate* is represented as the arc. In-order to be machine process-able RDF uses URI*ref*; a URI*ref* is a URI appended with # sign and an optional *fragment identifier*. Another utility of URI*ref* is that a set of a particular URI*ref* can be use to setup a *vocabulary*. Such a vocabulary can be defined by using *Vocabulary Description Language* also called RDF schema that includes the primitives to specify classes, subclasses, properties, sub-properties and relationship among them. As a language RDF also defines a vocabulary of its own. RDF provides

several primitive types such as rdf:ID and rdf:about others including *Containers*, *Collections* and *Reification*.

Web Ontology Language (OWL) (McGuinness & Harmelen, 2004) is the extension of RFD, it provides the necessary primitives to describe an ontology in a formal way. Two important aspects of any ontology language are its power of expressiveness and decidability of inference mechanisms. Based on these two issues OWL comes in three different versions

- o **OWL Lite** provides a classification hierarchy and limited constraints
- o **OWL DL** provides maximum expressiveness while ensuring computational completeness
- o **OWL Full** provides maximum syntactic freedom, however makes no guarantee about the decidability

An ontology consists of concepts (also known as Classes), relations (Properties), instances and axioms and hence a more succinct definition of ontology may describe it is as 4-tuple <C, R, I, A>, where C is a set of concepts, R a set of relations, I a set of instances and A set of axioms (J. Davies et al., 2006). OWL provides all the constructs needed to create an ontology, such as OWL *Classes* are used for presenting a concept (i.e. class), classes can have sub-classes. All classes in OWL are sub-class of *owl:Thing* class - and every class in OWL has a sub-class called *owl:Nothing*. It also allows classes to be defined through expression these classes are called *Anonymous* classes. OWL **Properties** extends the idea of *rdf:Property* and provides two kinds of properties *owl:ObjectProperty* and *owl:DatatypeProperty*. Each property can have sub-properties. *Individuals and Axioms* allow creating instances of both classes and properties. Axioms are used to make assertions about classes and properties.

4.2.4. Application of Ontologies In Mobile Learning

Ever since the concept of ontology has been coined in the field of AI, it has been extensively used in many other fields. When considering its applications in ML, **three** general/broad areas of its applications can be identified along with other less explored areas. The first broad area of its application is to use it for **Context Awareness**. The second broad area of its application is **Content Provisioning** and lastly for **Personalization**.

The notion of context has been widely debated and many different definitions of context can be identified in the literature. Uden (Uden, 2007) defines it as *"simultaneous interaction of a number of mutually influential factors. Factors such as physical, social and instructional aspects interplay to influence learning"*, while Dey and others (Dey, Abowd, & Wood, 1998) define context as "*any information that can be used to characterise the situation of an entity. An entity is a person, place or object that is considered relevant to the interaction between a user and an application, including the user and application themselves"*. Detailed accounts of context are presented by many authors (Abowd et al., 1999; Bradley & Dunlop, 2005; Öztürk & Aamodt, 1998; Zibetti

& Tijus, 2005), while (Baldauf, Dustdar, & Rosenberg, 2007; Bettini et al., 2010) provide overviews of how context is applied and modelled, Eljueidi (Eljueidi, 2011) discusses context from the view point of its application for CML.

For ML, ontologies have been used in many different ways to achieve different goals. Siadaty and colleagues (Siadaty, T. M. Eap, et al., 2008; Siadaty, Torniai, et al., 2008) present m-LOCO ontology which consists of several sub-ontologies, m-LOCO captures contextual information in ML environments and helps their system to assist instructor and learner by delivering appropriate learning objects. Berri and colleagues (Berri, Benlamri, & Atif, 2006) present a context aware ML approach based on a rule-based ontology to extract lightweight (in terms of bytes) learning objects. Hu and Moore (Hu & Moore, 2007) present a context template derived from ontology and construct a context middleware for supporting ML. Ahmed and colleague (S. Ahmed & Parsons, 2011) discuss ontology as a semantic model of ML to retrieve contextual data from different entities.

As highlighted earlier the content for ML is usually lightweight (in terms of bytes and attention required from the learner). Most of the time the aim of ontology based context aware ML is to adapt the learning content for mobile devices. Therefore, the discussion provided in the previous paragraph is directly related to content provisioning. In order to manage learning content, ontologies have also been used to attach meta-data with learning content (Pathmeswaran & V. Ahmed, 2009). Other examples of ontology application for content provisioning for ML have been discussed in (Auinger & Stary, 2007; Caballé, Xhafa, Daradoumis, & Juan, 2009; Yu, Nakamura, D. Zhang, Kajita, & Mase, 2008).

Applications of ontologies in ML for personalization mainly concerns recommendation, learner profile management, understanding learner's preference and psychology. Kim and others (J.-Y. Kim, J.-W. Kim, & C.-S. Kim, 2007) present an ontology based generic user model for recommending personalized information. Moore and Hu (Moore & Hu, 2007) propose an ontological framework for personalizing ML.

4.2.5.   User Profile Modelling Approaches[1]

Particularly relevant to this work are the applications of ontologies for user modelling. Several different approaches to formulate user model have been proposed and demonstrated in literature and practice. Sosnovsky and colleague (Sosnovsky & Dicheva, 2010) provide a comprehensive overview of different aspects related to user modelling. They define user model as a *"knowledge source in an intelligent system which contains assumptions on different aspects of the user that may be relevant to the system's adaptive behaviour. These assumptions must be separable from the rest of system's knowledge".* An important goal of different existing user modelling

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[1] In this thesis, reader should not mix the term "*Ontology*" with "*User Model*", user model is a part of complete ontology

approaches is to define a generic user model that is reusable for various application domains and can be used with no or slight modifications, extensions or adaptations. In general a generic user model can sufficiently describe various aspects of the user and when adopted by several systems, it can allow them to interoperate with each other on a semantic level. Among others the three commonly used generic user models are Friend of a Friend (FOAF) (Brickley & L. Miller, 2010), Unified User Context Model UUCM (Niederee et al., 2005; Niederée, Avaré Stewart, Bhaskar Mehta, & Hemmje, 2004) and GUMO (Heckmann, Schwartz, Br, & Kröner, 2005; Schwartz, Brandherm, Schmitz, & Heckmann, 2005).

FOAF: is targeted to support user profiles on the Web. The idea behind FOAF is to connect the scattered information about people on the Web. It allows to formally describe the relationships which connect people, things and places. However, it focuses more on the social aspects than the user profile. Thus, it aims at collecting information about interrelations among people and has weak support to describe the detailed aspects of the user profile. FOAF uses Resource Description Framework (RDF) (Manola & E. Miller, 2004) and provides a vocabulary, which uses popular vocabularies such as basic RDF vocabulary and Dublin Core metadata elements.

UUCM: while describing user model it concentrates its efforts in describing different user contexts and permits describing several working contexts of the user. It provides an extensible set of facts that can reflect different aspects of user profile such as skills and interests etc.; the same set of facts can also be used to reflect aspects of user situation and environment (Niederée et al., 2004). UUCM adopts an approach that divides the modelling complexity into two different levels of abstraction, namely abstract level and concrete level. Abstract level defines user context, user model facets, core properties for facet description, and user model dimensions. The concrete level defines an extensible set of facts which can be used to illustrate *Task, Relationship, Cognitive Pattern and Environment* dimensions of the user model.

GUMO: as a user modelling ontology it puts user at the centre and attempts to articulate a very comprehensive and detailed model to formally describe the user. As the name suggests GUMO is a general-purpose (i.e. top level) user model, it is very generic and can be molded to provide support in several different application areas. GUMO divides descriptions of user model dimensions into three parts: **auxiliary - predicate – range** (Schwarzkopf, Mori, Dengler, Kr, & Heckmann, 2007). It provides a set of basic auxiliaries to describe the user model and permits to capture different dimensions such as BasicUserDimensions, ContextDimensions, DomainDependentDimensions and SensorDimensions. Without going into the details of each dimension, these different dimensions of the user models make it possible to describe important aspects of user such as goals, interests, demographic, contact-Information, knowledge, preferences, emotional state, facial expressions, personality, psychological state, location, physical environment, social environment etc.

4.3. Summary

Technological support both in terms of hardware and software is necessary for developing purposeful applications of ML. Software agents have been proven to be very useful for other domains with dynamic attributes. While the domain of ML is still emerging there is a need to explore different types of support and benefits software agents can offer for ML. Ontologies allow formalization of domain knowledge in ways to make it useable by digital entities. Ontologies present a great potential for ML and already there have been several projects experimenting with application of ontology to assist mobile learners. Ontologies and software agents are already closely related, the need of the hour is to consider their application in ML. The discussion provided in this chapter clarified the concept of softwares and ontologies in general and particularly in relation to ML. Later chapters will develop on these understandings to explore the research results presented in this thesis.

Chapter 5

Framework of *Places* and *Spaces*[1]

[...] do not take **Place**[2] *to be something simply physical. A* **Place** *is not a mere patch of ground, a bare stretch of earth, a sedentary set of stones. What kind of thing is it then? The "what is" locution-Aristotle's* **ti esti** *question-combined with "kind of" suggests that there is some single sort of thing that* **Place** *is, some archetype of* **Place**. *But whatever* **Place** *is, it is not the kind of thing that can be subsumed under already given universal notions-for example, of* **Space** *and time, substance or causality. A given* **Place** *may not permit, indeed it often defies, subsumption under given categories. Instead, a* **Place** *is something for which we continually have to discover or invent new forms of understanding, new concepts in the literal sense of ways of "grasping-together." (Casey, 1997).*

In this last chapter of background studies, we will provide a brief discussion to articulate the concept of *Place* as something different from that of *Space*. Although there is no such thing as "*Framework of Places and Spaces*", however to comprehend theses two different concepts in a unifying way we will use the term "*Framework of Places and Spaces*" to refer to the theoretical literature that establish them as two different concepts. As we have briefly mentioned earlier and will discuss in later chapters, that in this work the *Framework of Places and Spaces* is applied to organize the different learning *Spaces* for providing automated support for CML. Furthermore, in this chapter we will also discuss "*Experience*" as a way through which the *Places* evolve and emerge. The concepts discussed in this chapter provide theoretical foundations which are used with software agents and ontologies to support CML. **Main aim**—of this chapter is to *present the theoretical explanation of Place that appears as an emergent overlay over physical Space.*

5.1. Rationale for Replacing *Space* with *Place*

It is a commonly understood reality that everyday life activities of individuals are attributed by time and *Space* of their occurrence. The relationship between *Space* as

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[1] The literature that discusses the concept of *Space* and *Place* is extensive, furthermore the concepts themselves are so general that they are related to many different fields such as architecture, urban planning, Computer Supported Cooperative Work (CSCW), philosophy, anthropology etc… Providing a comprehensive overview of these very vast and general concepts is beyond the scope of this chapter and is not relevant. Therefore, the discussion here is focused and limited to develop a clear understanding for applying these concepts for CML. Ciolfi and Rossitto (Ciolfi, 2004; C. Rossitto, 2009) provide a more detailed account of these two concepts in their PhD dissertations.
[2] Changed caps from the original

metaphorical object where human activities occur has been studied for providing technical support to effectively conduct the activities. The fundamental idea is based on the fact that one-to-one computer-human relationship provides an eliminative approach to understand human activities. Therefore, a better approach would to take a holistic view and also consider the other prevailing variables in the environment where human computer interaction occurs. For this purpose several studies and experiments have been conducted to model and augment the *Space*s, few of such examples are presented in (P. Dourish, 1993; P. Dourish & V. Bellotti, 1992; Paul Dourish, Adler, Victoria Bellotti, & Henderson, 1996; H.-w Gellersen, Beigl, & Albrecht Schmidt, 2000; Sawhney, Wheeler, & Schmandt, 2001; A. Schmidt, 2000; Albrecht Schmidt, Beigl, & H.-W. Gellersen, 1999; Sparacino, 2002; N. A. Streitz et al., 2003). Ciolfi (Ciolfi, 2004) summarizes different approaches into three general categories. In her view the technical research to model space is focused on:

- o Modelling the structural features of physical environment into technical system through the use of sensing devices
- o Adding different artefacts to create an overlapping of different layers of physical and digital information within the physical *Space*
- o Creating links between digital and physical *Space*s and thus redefining barriers between local and remote environments

During different studies the utilization of *Space* as physical entity augment with digital technologies showed promising results. However, just attaching activities with physical *Space*s provided a very focused and narrowed approach to analyze the complex and rich activities. To this end, Ciolfi (Ciolfi, 2004) states that "*more complete understanding of human interaction within the physical space can be achieved through the analysis of the experience of that space, and specifically extending the interest from the mere structural analysis to an experiential analysis of the Space*". The suggestion is therefore, to consider a more sophisticated conceptualization that can carry in its explanation not only the attributes of physical aspect, but also associated feeling, emotions, meanings, understandings etc.

In CSCW the term *Place* was introduced by Harrison and colleague (Harrison & P. Dourish, 1996) to replace the *Space*, as they state "*We are located in 'space', but we act in 'place'". Space relates to the physical world, Place is Space invested with values and meanings (C. Rossitto, 2009).* From the terminological point of view there does not seems to be much difference between the two terms, in fact the two terms may appear to be somewhat confusing to a newcomer. However, when used as an analytical tool the real power of these different conceptualization become evident. A new notion that has emerged by making such distinction is "experience", it acts as the rich pathway that allows moving from the dominantly physical notion of *Space* to higher level notion such as *Place* without losing affiliated significance. Making such a distinction has greatly contributed to the field of CSCW (Fitzpatrick, Kaplan, & Mansfield, 1998; Harrison & P. Dourish, 1996; Harrison & Tatar, 2008; Healey, White, Eshghi, Reeves, & Light, 2008; Ponti & Ryberg, 2004) and interaction design (Ciolfi, 2004; McCarthy & Ciolfi, 2008; Paay & Kjeldskov, 2008).

5.2. Conceptualization of *Space*

According to Britannica Online Encyclopedia[1] *Space* is *"a boundless, three-dimensional extent in which objects and events occur and have relative position and direction"*. *Space* is the actual landscape that exists in the physical world and has tangible properties, thus can be quantified in units. In other words, it is a piece of land that has geographical coordinates and has some boundaries. It consists of the physical objects that are present within its boundaries. Physical objects which exists in *Space* are the people and the interesting locations that are present inside its boundaries. The attributes belonging to *Space* are normally static. An example of a *Space* could be a church, which consists of different physical objects such as statues, painted walls etc… and people who are present in the church.

This being said, we must also mention that the concept of *Space* has been debated in different branches of science such as *Environmental Psychology*, *Mathematics*, *Physics*, *Geography* and *Psychology*. Therefore the interpretation of the term "*Space*" is contextual in different disciplines. Ciolfi (Ciolfi, 2004) provides a detail discussion about different theoretical accounts explaining *Space*. In the context of this thesis, we will only consider the geographical approach that measures the *Space* in terms of latitude/longitude.

5.3. Conceptualization of *Place*

While *Space* is static, *Place* is a multi-dimensional concept and is dynamic in its nature. It has intangible properties and is hard to quantify. Like *Space, Place* has also been discussed in many different disciplines, such as geography (Buttimer & Seamon, 1980; Sack, 1986; Y. - F. Tuan, 1975; Y.-F. Tuan, 1989; Y.-F. Tuan & Hoelscher, 2001), philosophy (Casey, 1993; 1997; 1998), architecture (Alexander, 1979), anthropology (Low & Lawrence-Zunigais, 2003) etc…

Particularly relevant to this work are the geographical and philosophical explanation of *Place*. Understanding geographical elicitation of *Place* is important because we will apply it for supporting CML. The philosophical explanation is important because it rationally revels the truth about *Place* in a thoughtful manner. Philosophical explanation is also important because, proposing a fancy term is just the point of departure, but to arrive at the destination a detail elicitation is needed. Furthermore, although the term *Place* has been discussed in literature, but its articulation is very patchy and incomplete, therefore a philosophical explanation of *Place* can provide a valuable insight into the very nature of the term *Place* itself. We will now provide a brief overview of Tuan's and Casey's explanation of *Place*.

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[1] http://www.britannica.com

5.3.1. Tuan's Explanation of Geographical *Place*

Tuan as a geographer believes that the notion of *Place* has been approached in two different ways in geography, firstly as a location (i.e. *Space*) and secondly as a unique artefact (Y. - F. Tuan, 1975). In this sense *Places are points in geographical system, but at the opposite extreme they are strong visceral feelings.* In his view *"Place is a center of meaning constructed by experience".* The debate provided by Tuan strongly suggests that the experience of a *Place* is not only based on the sensory input such as touch, seeing etc… but is more abstract such as thoughts and feelings. Four main dimensions characterize Tuna's articulation of experience of *Place*. The first and the most obvious is the **Physical dimension**: which relates to the physical characteristics of the *Place*. **Personal dimension:** is related to the personal beliefs, thoughts, emotions and feelings. **Social dimension:** is the presence of others within a given *Place*, and **Cultural dimension:** code of conduct, rule and norms prevalent in the *Place*.

5.3.2. Casey's Explanation of Philosophical *Place*

Casey as a philosopher discusses *Place (Casey, 1993; 1998)* as an emergent concept based on how individuals experience it. From this standpoint *Place*s evolve over time and have no static attributes. As different activities occur in a *Place,* its understanding among its occupants is renegotiated and redefined. It is not only the *Place* that is influenced by experience of individuals, but the inverse is also the case. Thus, on one hand *Place* is influenced by experiences and activities, while on the other hand experiences are influenced by *Place*. Thus, *Place* is a product of individual experiences and activities. An important aspect of Casey's *Place* is its lived dimension; this is to emphasize the presence of individuals who live in a *Place* and experience it.
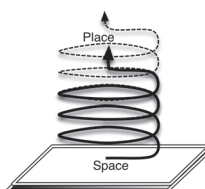
Figure 10: Relationship between Space and Place

When an individual visits a *Space*, [s]he develops a personal understanding of that *Space*. The understood meaning of a *Space* when attached to it transforms it into a *Place* for that particular individual. In this sense a *Place* is a specialization of *Space* with attached meanings. Figure **10** depicts the relationship between *Space* and *Place*. The perceived meaning of a *Space* results in the construction of a personal experience of a *Place*. From an individual's point of view [s]he performs activities in a *Place* consisting of other individuals and like other individuals his/her experience of the *Place* is reflected in the properties of that *Place*. *"A given Place takes on the properties of its occupants, reflecting these qualities in its own construction and description, and*

expressing them in its occurrence as an event: places not only are, they happen" (Casey, 1997). Every time an individual visits a *Place* which [s]he has previously visited, his/her experience builds on the previous experiences of that *Place* and evolves. Since each individual can develop a unique experience of a *Place*, therefore, there can exist several *Places* over a *Space*.

Local knowledge, then, comes down to an intimate understanding of what is generally true in the locally obvious; it concerns what is true about Place in general as manifested in this place. Standing in this Place thanks to the absolute here of my body, I understand what is true of other Places over there precisely because of what I comprehend to be the case for this Place under and around me. This does not mean that I understand what is true of all Places, but my grasp of one Place does allow me to grasp what holds, for the most part, in other Places of the same region. My ongoing understanding of surrounding and like Places is characterized by essential structures manifested in my own local Place and illuminating other places as well. That anything like this induction of Place is possible exhibits Place's special power to embrace and support even as it bounds and locates. (Casey, 1997).

Casey suggests **Event** as a metaphor to understand *Place*. In other words *Place* occurs as an **event** to an individual and emerges over time; two main factors which contribute to the emergent nature of *Place* are the evolving nature of the experiences and the movement of the learners within *Place*. *Place* can be experienced alongside following dimensions. **Psychological Dimension:** relates to an individual's personal memories, thoughts and beliefs. **Physical Dimension:** is how the physical structure (i.e. *Space*) of a *Place* supports or hinders the activity the individual is doing in a *Place*. **Historical Dimension:** is related to individual's past memories of a *Place*. **Social Dimension:** is about the presence of other individual in a *Place*. Casey proposes the following three different kinds of movements of individuals inside a Place: ***1) Staying inside a Place, 2) Moving inside a Place and 3) Moving between Places.***

5.4. Technology as Experience

The term experience is thoroughly discussed from geographical and philosophical perspective by Tuan and Casey respectively. However, their elicitation of experience is particular to their discipline of interests. Therefore, in order to elaborate and explain experience of a *Place* that occurs through the use of digital mobile device (in case of CML), it is important to also take into account the involved technological factor. McCarthy and Wright (McCarthy & Wright, 2004; Wright, McCarthy, & Meekison, 2003) suggested a framework that discusses technology as experience. It highlights different technological aspects which are missing in the other theoretical elicitation (i.e. Casey's explanation of experience). Four intertwined threads and six sense making processes characterize McCarthy and Wright's framework.

- o *Compositional Thread:* how the experience is assembled through the interplay of different sub-parts of the experience, which fit together to form a coherent whole. *"Refers to the narrative structure, action possibility, plausibility,*

consequences and explanations of actions" (McCarthy & Wright, 2004).
- o **Sensual Thread:** informs about feelings perceived from the overall impression of environment. Social settings, look and feel of the environment are some of the factors influencing this thread.
- o **Emotional Thread:** emerges from the emotional response resulting by using the technology (e.g. joy or frustration).
- o **Spatiotemporal Thread**: is related to the effect of place and time over experience.
- o **Six Sense making processes:** these are reflexive and recursive processes through which people actively make sense of their experience. These are **1) Anticipating:** prejudice about technology. **2) Connecting:** accounts for the immediate understanding which is developed very quickly when we first look at a technological artefact. **3) Interpreting:** is about associating meaning to current situation. **4) Reflecting:** Deciding or making judgement about what is possible/impossible/difficult/easy by using an application. **5) Appropriating:** how new experience fits with our previous experiences. **6) Recounting:** a dialogical process through which we tell others and our self about our experience.

McCarthy and Wright's framework of experience targets individual's experience from the perspective of technology. Thus, experience is not an isolated feeling, but it is created through the use of technological artefact.

5.5. *Space*, *Place* and Experience for ML

Different approaches have been used to model the learning *Space* for ML. The main aim of these approaches is to track the position of learner in the learning *Space*. By knowing the position of the learner it is possible to communicate with a mobile device of the learner in a context aware manner. Technologies such as WLAN(802.11a,b,g)[1], IrDA[2], RFID[3], GPS[4], QR code[5] etc… have been used for detecting user's position in the learning *Space*.

Different projects such as *Cyberguide* (Abowd et al., 1997), *Uncle Roy all around you* (Benford et al., 2004), *Can you see me now?* (Benford et al., 2006), *Savannah* (Benford et al., 2005), *Massey Mobile Helper* (R. Brown, Ryu, & Parsons, 2006), *Mobile and Ubiquitous Learning* (MoULe) project (Gentile et al., 2007) model the ML environment by pre-programming the location of object in the learning environment and by detecting learner's location (mainly though the use of GPS technology) among different learning objects. While all these works pay serious attention to model spatial aspects of the ML environment, they do not account for the meaning that learners associate with the

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[1] http://en.wikipedia.org/wiki/Wlan
[2] http://en.wikipedia.org/wiki/Infrared_Data_Association
[3] http://sv.wikipedia.org/wiki/RFID
[4] http://en.wikipedia.org/wiki/Global_Positioning_System
[5] http://en.wikipedia.org/wiki/QR_code

Spaces. In other words they completely dropout the idea of *Place*. Many works have considered user's experience (Benford et al., 2004; Galani et al., 2003; Gentile et al., 2007; Parsons, Ryu, & Cranshaw, 2006). The experience as they describe is somewhat mythical, they do not clarify what exactly learning experience constitutes of.

5.6. Summary

This chapter has provided an overview of two important concepts, namely *Space* and *Place*. While providing an understanding of these concepts, we have been careful not to introduce any new explanation of these terms. Both the terms are well established and elaborated in the domains of their application. *Space* is a physical entity and *Place* provides a somatic approach to associate rich semantics to a *Space* (i.e. physical location). Supporting the process of experience that occurs when an individual visits a *Place*, is actually the support provided to an individual to develop understanding and gain knowledge. These theoretical foundations are very relevant to CML and their application in CML provides a higher-level approach to analyze and provide technical support for CML.

Part III -- Research Results

Chapter 6

AGORA Based Citywide Mobile Learning Framework

"[.....] the changed learning environment must be understood by systems and technological facilities must be provided for knowledge sharing and construction. Such systems need to be [...] adaptive to altered modalities. The teacher who was once the central entity to fulfil the learner's needs may not always be available. Therefore systems would fill the gap created by this teacher unavailability by actively participating in learning activities and performing some of the teacher's roles (A. B. Khan & Matskin, 2009).

This chapter will present three important sub-results of the work conducted during this PhD. The first important sub-result presented in this chapter is the *extended version of the AGORA framework,* which is applied to support *Place/Space* based CML. The second sub-result is an *agent oriented software engineering methodology* that can be used efficiently to design Multi-Agent Systems (MAS) based on the AGORA framework. Finally, the last part of this chapter will present the *FABULA Framework for Citywide Mobile Learning* (FFC-ML). **Main aim**—of this chapter is to **present the frameworks designed to support CML to fulfil the technical goals of FABULA project**.

6.1. Extended AGORA Framework

 AGORA follows the metaphor of market place that provides support for conducting collaborative agent activities. Therefore, it acts as a cooperative node where agents come together to conduct certain activities. The node then provides services such as management, coordination and negotiation related to the activity at hand. Many different AGORAs can be started in the system to provide support for complex cooperative activities. Three AGORA-Manager-Agents present in every AGORA provide the required support. These are AGORA-Manager, AGORA-Coordinator and AGORA-Negotiator; each of them provides services to handle the activities involved in a cooperative activity. The framework proposes solutions to several problems involving software agents and services. Following are the main objectives of the AGORA framework:

o Provide clear separation between an agent and its services
o Allow an agent to provide and consume different kinds of services (e.g. FIPA and W3C based services)

o Emphasis on communication, coordination, negotiation and management aspects of software agent
o To facilitate the design of Multi-Agent System that can scale in open environments
o Efficient discovery/locating the services in a peer-to-peer (P2P) fashion, without the need of a central repository.
o Promoting adoption of standard for future extensibility and interoperability

The AGORA framework is positioned at the intersection of two aspects of software agents discussed previously. Firstly it is a Multi-Agent framework, which is general enough to be adoptable in a number of situations and domains. Furthermore, the framework is extendable and if needed it is possible for developers to override the base functionality. This means that the framework provides a high level functionality that can be overridden/extended using "low level" tools (like Java) when needed. Secondly, the AGORA framework enables agents to consume and provide different types of service (i.e. FIPA, W3C). The approach adopted by AGORA does not uses a dedicated *Gateway* entity for performing translations. Instead it enables software agents to understand both FIPA and W3C. Not all the standards from W3C need to be understood, but only the important ones.

6.1.1. Model of AGORA

An AGORA is tailored to support a special kind of functionality; therefore the functional support provided by the sub-components (i.e. AGORA-Manager-Agents) of AGORA is in coherence with the nature of its usability. An AGORA consists of four main components as depicted in Figure **11**, an AGORA-Node, AGORA-Manager-Agents, AGORA-Services and Registered-Agents.
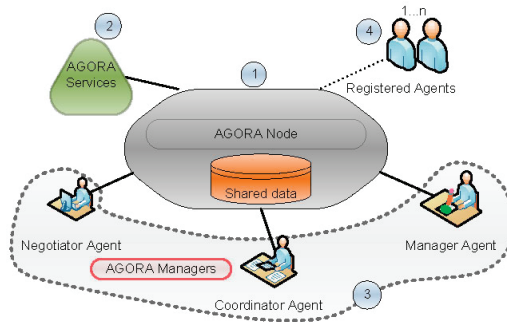
Figure 11: Simple model of an AGORA

AGORA-Node: This is at the core of everything. This node contains all critical data related to AGORA. This data is shared among all the AGORA-Manager-Agents. Every AGORA is started with starting this node. All AGORA-Manager-Agents and *Services* are initialized at the start-up of the AGORA-Node. From the resource point of view, this node can also be considered as a database that contains information about locators of the AGORA-Manager-Agents (i.e. the contact points where the managers can be reached).

It also contains the description and locators of services provided by AGORA. Along with the descriptive information of AGORA (i.e. name, textual description etc), the other information kept in *AGORA-Node* is about *Registered AGORA*s and Registered Agents [discussed later].

AGORA-Services: Each AGORA can provide an arbitrary number of services. These services are different from the services provided by the AGORA-Manager-Agents (i.e. management related services). The functional context of these services matches the overall context of the AGORA. These services may either follow W3C or FIPA. For this reason we generalize the services as resources. From implementation perspective any kind of services can be searched and invoked. Each service can provide its own description, in our work we only support WC3, FIPA service description. Thus, AGORA provides a unifying view of W3C and FIPA. Among the *AGORA-Manager-Agents* the AGORA-Manager is responsible for providing access to services; so it is the host for services. However, AGORA-Manager-Agent is not just responsible for managing services, but it also provides its own services which are treated separately in our architecture.

AGORA-Manager-Agents: These are agents responsible for providing management support services for an AGORA. All the Managers support FIPA-ACL (as content language) and SOAP messaging (for service invocation). An AGORA has three different AGORA-Manager-Agents. First AGORA manager named **AGORA-Manager:** is responsible for performing the overall operations related to the management of AGORA. It is responsible for registration and un-registration of other AGORAs and agents (i.e. *Registered agents*) in the AGORA. It maintains all data in the *AGORA-Node* and insures that the information about the AGORA (i.e services and agent locator) is up to date. Apart from management related activities, this agent provides access to the *AGORA-Services*. The second AGORA manager is named **AGORA-Coordinator:** implements logic that insures the smooth flow of collaborative activities. For every activity (i.e. communication protocol) that an AGORA supports there is a workflow describing the activity (i.e. participant A must send a message and in response to that message participant B must send another message etc). The AGORA-Coordinator insures that all participants of the activity follow the rules prescribed in the workflow. **AGORA-Negotiator:** This is the third and last AGORA manager that implements logic of conflict resolution for all supported activities of AGORA. By default the contract-net protocol is used. However, other protocols can be provided as well.

Registered-Agents: These are external agents who would like to use functionality provided by AGORA. All agents who wish to use the functionality of the AGORA have to be registered at the AGORA. These agents communicate with the AGORA-Manager-Agents by message passing and consume AGORA-Services when needed. Each AGORA can have any number of registered agents. The AGORA framework does not impose any restriction on the internal model of these agents; the only requirement is that they should be able to send/receive ACL or SOAP messages.

From a programming (i.e. AGORA based development) point of view a base structure of AGORA is provided along with the basic functionality pre-programmed for each sub-component of AGORA. The implementation includes communication protocols for all the AGORA-Manager-Agents which are discussed later. The AGORA-Node services are also part of the implementation. A developer can extend, add or override the functionality of each AGORA.

6.1.2. AGORA Parent Child Relationship Tree

Several different AGORAs can be combined together in a network where each AGORA is tailored to provide different services and management functionality (provided by AGORA-Manager-Agents). Upon creation of a new AOGRA it is added into a graph of already running AGORAs. This approach allows the system to be extended in an incremental fashion. At the same time any external agent who is interested to use some functionality can search and register with as many AGORAs as it needs. Since an AGORA can be developed by extending an already existing AGORA, a programmer can easily create new AGORAs from the existing ones. In this way the complete network of AGORAs can be viewed as a bucket of functionality where any interested party can use or add new functionality.
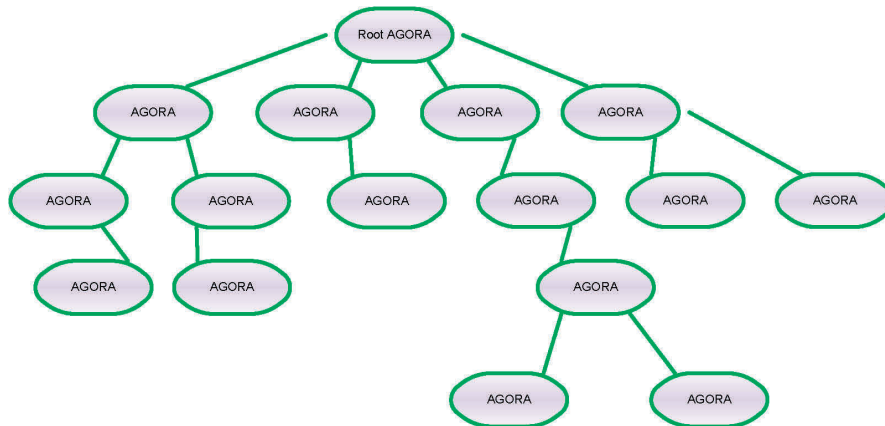
Figure 12: AGORA parent child tree

Whenever the AGORA system is started, an AGORA called *ROOT AGORA* is started in the system as depicted in Figure **12**. The *ROOT AGORA* is responsible for common tasks related to management (i.e. GUI updates etc.). Every AGORA has another AGORA as its parent with exception of the *ROOT AGORA* who is created by the system but not by other AGORAs. This means that an AGORA can only be started by another AGORA and upon start-up the information related to parent and child is exchanged between AGORAs. It is worth mentioning that no references of AGORAs are exchanged -- instead the exchanged information is a combination of locators of AGORA-Manager-Agents, information about AGORA-Services and other information such as security keys, description, names etc. Every AGORA, when it starts, also publishes/advertises its information in the parent-child tree which is managed as a *Static*

structure in the system and is accessible to all other components of the system. Furthermore, at any moment an AGORA can update its profile in the tree as changes occur. The parent-child graph can be searched to discover resources available in the system.

6.1.3. AGORA as P2P Service Repository

Parent-Child relationship supports a static approach to search resources. A complementary approach that exists in the AGORA is a peer-to-peer approach, where each AGORA behaves as if it is a peer node in the system.
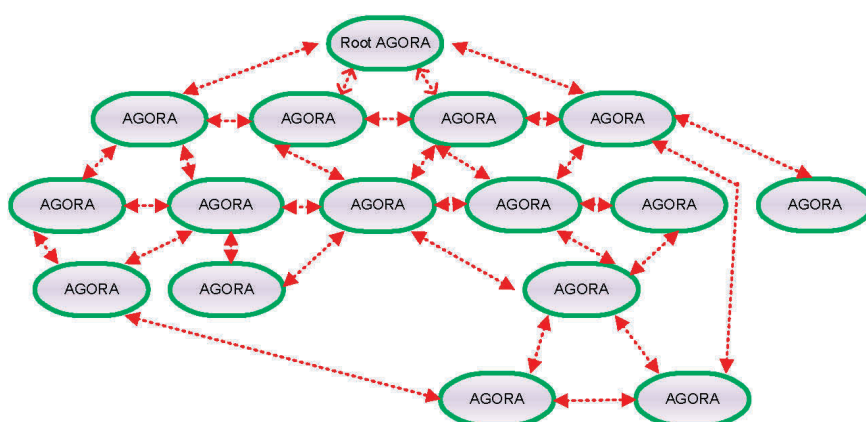
Figure 13: AGORA registration graph

Any AGORA in the system can register with any other AGORA as required. The main reason for such registration is to consume/provide services. When an AGORA registers with another AGORA, both AGORAs exchange their information. Figure **13** depicts a possible graph of registered AGORAs. In such a graph when an AGORA is requested to provide some services, it first looks if it can fulfil the request. If it cannot then it looks into the cached information about the other registered AGORAs. If these AGORAs are also not capable of providing the required services then the request is broadcast to all the registered AGORAs who may have cashed the information about the provider of the requested resource. This approach is identical to 2nd generation P2P networks (i.e. Flooding-Based systems) such as Gnutella (Minoli, 2004).

6.1.4. AGORA-Ontology

Since AGORA considers agent communication, coordination and negotiation in open distributed environments it is important that the system entities use a standard ontology when they interact with each other. The AGORA system incorporates an ontology that mainly consists of two parts. Firstly it provides a formal specification of AGORA's data model (i.e. what kind of relationships exists between sub components of AGORA). As shown in Figure **14**, AGORA-Ontology formally captures the main components of the

AGORA framework, inverse of relationships not shown in Figure **14** are also present in the ontology.
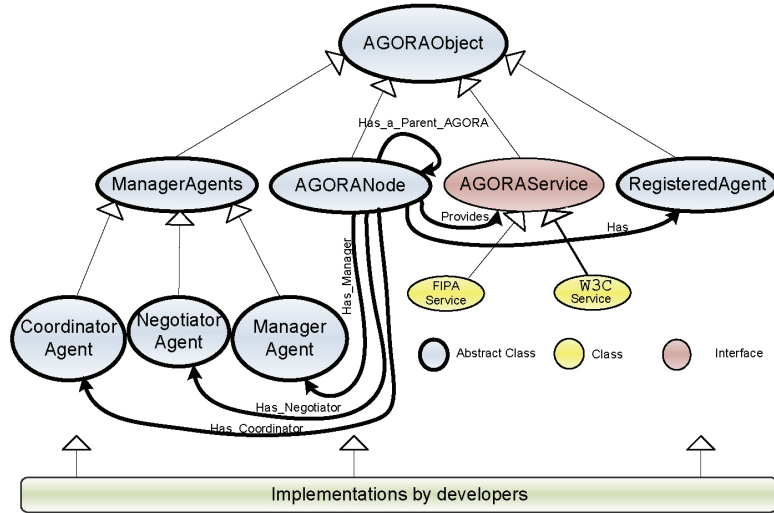
Figure 14: Abstract view of AGORA-Ontology

Secondly, it specifies main actions that can be performed by agents in AGORA (i.e. AGORA-Manager-Agents and Registered-Agents). These actions are pre-programmed in the base implementation of AGORA. The Figure **15** depicts the basic pre-programmed actions that can be performed by agents in all AGORAs.

Figure 15: Ontology of Manager Agents Actions

Availability of such ontology allows the AGORA-Manager-Agents and the *Registered-Agents* to reason about each other. Furthermore, each AGORA-Manager-Agents knowledge base is also constructed from this ontology. Fragments of this ontology appear in the messages that are transferred among the AGORA agent. For example, when an agent wants to register with AGORA it sends a message requesting AGORA-Manager to perform its *RegisteredAgent* action in response to the request.

6.2. AGORA Based *MAS* Engineering Methodology

AGORA MAS Software Engineering Methodology (**A-MASSEM**) proposes a general agent oriented software engineering approach that encourages convergence of domains/technologies so they can be useful to each other and to the users. Thus, A-MASSEM is a *higher-level Multi-Agent System engineering approach* that allows the future changes/evolution and adapts readily to open environment such as Internet. It is motivated by the fact that most of existing agent oriented software engineering methodology pays less attention to the social aspects of Multi-Agent Systems. In contrast to the existing approaches, A-MASSEM considers Multi-Agent Systems as agent ecologies. Different agent ecologies can work together and act as Multi-Agent ecosystem. In such an ecosystem the social aspects of the agents are well defined and all the sub-components of the Multi-Agent System work together to achieve a fine integration of the whole ecosystem. While A-MASSEM pays due attention to the internal model of entities (i.e. Internal Model of Software Agents), this however, is not the main theme of A-MASSEM. Instead A-MASSEM attempts to capture the dynamic and social behaviours of agents by focusing on the cooperation, coordination, negotiation and management attributes of the system. From an implementation point of view, the A-MASSEM is grounded in the AGORA framework and the concepts developed using A-MASSEM can be mapped to implementation easily.

6.2.1. Ecological Perspective on Multi-Agent System

A-MASSEM borrows the conceptualization of *digital ecologies* from Nardi's book *"Information Ecologies: Using Technology With Heart"* (Nardi & O'Day, 2000) and views Multi-Agent System as an information ecology. An information ecology is defined as *an environment where different participating entities of a system along with their social practices have harmonious relationship with technology and among themselves and there is a considerable balance among the actions of all those who exist in the information space*.

Information ecology consists of the following subcomponents as described by (Nardi & O'Day, 2000). **(1) System**: this is to say that there is a relationship among the participants of the ecology and therefore whole system acts like a single entity. One participant getting affected or failing to function has an impact on the others and thus can result in disturbance in the system's behaviour. **(2) Diversity:** of skills and knowledge is another important aspect of information ecology, a healthy information

ecology is likely to have participants with diversity of skills and knowledge. **(3) Co-evolution:** This means continues change in a balanced way. Information ecology is never static; there is always a change that allows the knowledge and tools inside ecology to evolve. **(4) Keystone Species:** Keystone species are entities/service that are extremely important for the survival of the ecology. Unavailability of these species can be catastrophic for the ecology. In information ecology these are entities/services whose presence is necessary for the survival of the whole ecology. **(5) Locality:** To whom the technology belongs? What business, cultural region and users are using it? What is it used for? In information ecology a particular technology is associated with a particular group. These entities define the meaning of technology, thereby putting technology directly under the control of its context.

6.2.2. A-MASSEM Methodology

A-MASSEM considers a Multi-Agent System from two different perspectives: *active* and *passive*. While elaborating the two different perspectives or a Multi-Agent System, A-MASSEM iterates over all the aspects discussed by (Nardi & O'Day, 2000).

6.2.2.1. Active Perspective

During this perspective the Multi-Agent System is considered as a *set of active system entities* interacting among themselves and with external entities. The focus here is on the dynamic/social aspects of the system at runtime. The behaviour of the system is considered from the point of view of the user/agent who will be using the system (i.e. the occasion and reasons when external entities would want to interact with the system). Generally speaking during the active system perspective participants and cooperative points are defined. This perspective consists of two different steps.

Understanding the *SYSTEM*: During the first step the cooperation point or the cooperative activities the system will engage in are identified. In principle, overall social aspects of the system to be designed are analyzed. In this step the interested partners (i.e. Agents) are considered as the central point of the activity. This allows previewing the system's functionality from an agent's point of view. The major focus here is to identify the agent involved in a cooperative activity. Such cooperative points can be identified by understanding the application domain of MAS. For example, a possible cooperation point between a financial bank and a retailer is when the retailer want to verify a credit card, or to make a transaction from the credit card's holder account to the retailer's account. The process is depicted in Figure **16**. The cooperative activities are identified based on possible scenarios. The result of this step is a list of all perceived/possible points of cooperation.

Figure 16: Identifying the cooperative points
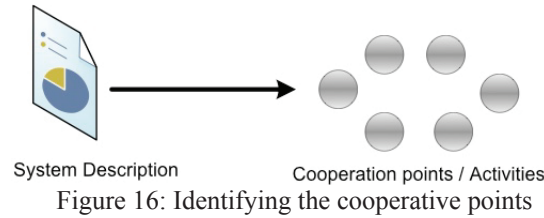
LOCALIZING System's Dynamics: During the second step coordination and negotiation support required for each cooperative activity are identified. We consider negotiation and coordination as the vital aspects of any activity in Multi-Agent Systems. This is depicted in Figure **17**, where the coordination and negotiation aspects surround a cooperative activity and they are required in order to execute an activity in intended way. Such activities are considered as cooperative nodes which are mapped to AGORAs and they may require coordination and negotiation support from other sub-components of their respective AGORAs.

Figure 17: Conceptualization of management, coordination and negotiation support for a cooperative activity
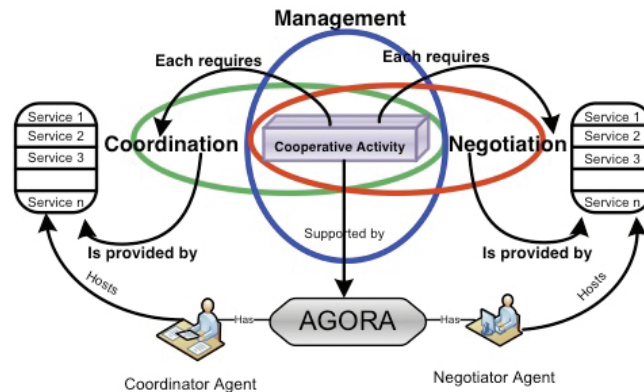
In the AGORA framework, while the AGORA-Manager is responsible for providing access to the AGORA-Services, the AGORA-Coordinator and AGORA-Negotiator are responsible for providing coordination and negotiation support. In terms of implementation the required coordination and negotiation support is presented as services supported by AGORA-Coordinator and AGORA-Negotiator. In this way when a cooperative activity is executed it is possible for a Registered-Agent (i.e. external entity) to know who should be contacted in case coordination and negotiation support is needed.

The AGORAs identified in this step can be created for different applications as needed at the runtime. Thus, several instances of Application AGORAs can exist in the system. These AGORAs are called *application level AGORAs*. The design and functionality of such AGORAs are defined for each application differently. Even within the same application, the behaviour of the application AGORA(s) may vary depending on different contexts and configurations. These AGORAs integrate the domain concepts of

the application in which they are used. They are created as generic templates, which already contain the basic and important functionalities. However, if needed, they can be extended and/or overridden to support more complex functionalities.

 This step also sets the requirements for the application services (i.e. *Required Application Services*) which are needed to perform the cooperative activity. This means that we make a differentiation between the services required to perform a cooperative activity and the services required to coordinate and negotiate about a cooperative activity. The AGORAs identified during this step are further elaborated in the passive perspective (discussed later). By virtue of this step the system's dynamic/social behaviours are localized to the type of activities it needs to perform. More cooperative points can also be identified and added later during the system's lifetime in order to adapt if changes are introduced. This is necessary as it may be difficult to envision all the possible applications supported by the system at the design time. Therefore, such step can be performed many times during the system's lifetime.

6.2.2.2. Passive Perspective

In the passive perspective the main goal is to define services that the system should have in order to execute cooperative activities identified in the previous phase. Another goal of this perspective is to identify the system's components who would be the providers or hosts of the required services. At this stage the system is treated as a static collection of functionalities. The whole process is divided into the three main steps as depicted in Figure **18**.
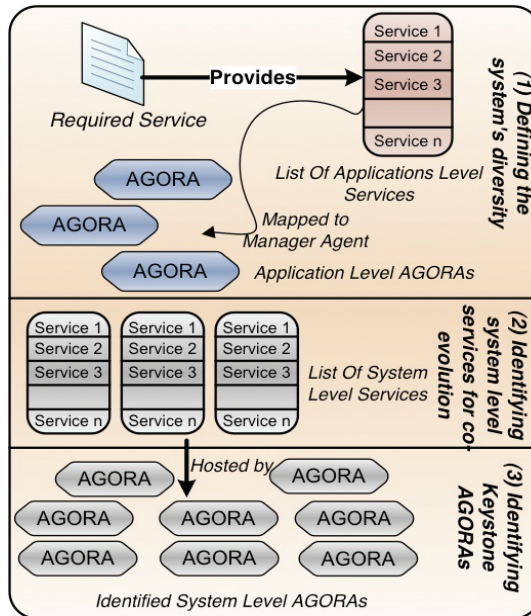

Figure 18: A summary of passive perspective

Defining the System's DIVERSITY: During the first step the main purpose is to derive the list of *Required Application Services* that are needed in order to execute cooperative activities. The requirements for the types of operations for these services are set in the previous phase [see section 6.2.2.1]. These services are called *application services* as they allow the system to perform its function in a cooperative activity. These services are mapped into the AGORA-Manager of respective AGORAs identified in the previous step. Iterating against the required functionality further refines the list of these services. The output of this phase is the minimum number of services that are necessary for the system to function.

Identifying System Level Services for CO-EVOLUTION: During this step more services are identified to extend the system's functionality for future adaptability and extensibility. While the main purpose of the AGORAs and services identified in the previous two steps were to perform the application level functions, the purpose of these services are to perform system level operations. Therefore, these are generic services that can be used without consideration of their application/invocation context. Our understanding is that, the application level services are specific to their respective applications and it is wise not to mix the system level functionality with application service. Consequently more services and applications can be supported by the system when the core services are available. This makes the system more capable of supporting new applications and activities. The services of this phase are called *system level services*. They provide basic/common system level functionality and allow more complex applications to be built on the top of the basic functionality allowing the system to evolve for future changes. An example of such service can be a service that checks the credentials of a user. Since the AGORA framework allows adding new AGORAs and services in the system dynamically the system can evolve as changes and new requirements occur in the future.

Identifying KEYSTONE AGORAs: In the last step the *System Level AGORAs* are identified. These are AGORAs who would be the providers of the system level services identified in the previous step. The number of identified AGORAs may vary depending on the nature of the system and the number of identified services. At most one instance of each such AGORA can exist in the system. Collectively all the AGORAs identified in this step define the core architecture of the agent system. Some examples of such AGORAs could be *ontology manager AGORA, repository manager AGORA* etc. These AGORAs are the providers of the core functionality of the system.

6.3. Framework for Citywide Mobile Learning

All the frameworks discussed during Chapter 3 are intended to be abstract enough to be adoptable to a very wide scope of learning systems. Many of these frameworks are successfully adopted and their actual implementation does exist. As also highlighted earlier, apart from few exceptions most of them mainly focus on the delivery of learning content to the learner while having no consideration for mobility. In other words they act as passive mediums of asynchronous communication between teacher and students. There is hardly any framework that attempts to support informal ML.

Introduction of autonomous and proactive entities such as software agents at the framework level can greatly improve the situation. By allowing the possibility of proactive system's behaviour in a dynamic setting such as in case of informal ML. Particularly in case of CML where learning takes place in city, such as that addressed by FABULA. In the dynamic environment that exists in cities the importance of proactive behaviour of the learning support system is paramount and cannot be neglected. However, there is lack of integration of such concepts in the previously discussed frameworks. It can be argued that just having mailing lists and threaded discussions is not enough. Most of the frameworks have limited support and adoptability as they do not consider the fact that learning takes place in real time. Therefore aspects of learner's mobility and the learning activity should be taken into consideration. This can be done by following and assisting the learner throughout the learning process, through recommendation and filtering of relevant learning material, by understanding and evaluating the spatial aspects of learner and adjusting the system's behaviour accordingly, and thereby personalizing the learning experience for each individual learner.

FF-CML incorporates *software agent* as a central entity in its design. All the theoretical aspects (i.e. *Place/Space*) of CML are blended in design and reflected in the components (i.e. agents and services) of the system. Ideally the applications of our system allow the inhabitants of the city to fulfil a specific learning need within a specific learning *Space* through the use of information and communication technology. By virtue of such a framework it would be possible to develop CML support systems which carry the potential of transforming the mobile communication infrastructure of the city into an active medium for learning.

Generally speaking the FF-CML can be divided into two main parts. The first part consists of the Service-Model (depicted in Figure **20**), which deals with the services or the functionality supported by the system. Services in FF-CML's Service-Model are organized into three different levels. At these levels services are categorized into twelve main categories. All the service categories in the *Basic Learning Services* and *Resource Management Services* are the lifeline services. In this way these categories are extremely important for the system's execution. While discussing the services in the later subsection we deliberately omit the names of common services and only mention the names of services that are more interesting for ML.

The second part of the system consists of the *Multi-Agent System,* also called **FABULA Multi-Agent System (F-MAS)** (depicted in Figure **19**). The mobility aspects of learners are taken care of by the F-MAS that operates at every level of the system, the inclusion of the AGORA framework allows to cope with the dynamically changing environment of CML. In this way FF-CML does not only suggest services for supporting CML, but also propose AGORA based MAS that is finely tuned to provide the identified services.

The design approach adopted to produce FF-CML is based on A-MASSEM, and it also takes valuable input from the already existing frameworks by perusing their established principle of employing a service-based approach and distributing the services into layers

and categories of system functionality. To present FF-CML we will now go through the five steps of A-MASSEM presented in the previous section.

6.3.1. Main Requirements for FF-CML

In order to elaborate and explain FF-CML that is created using A-MASSEM, it is important to briefly outline the main requirements that FF-CML is intended to fulfil. Most of the requirements discussed here are strongly connected to the FABULA project description and WPs, some of these requirements were also discussed in section 1.2.

Core requirements of FF-CML can be summarized as follows[1]. The FABULA system is a SERVICE BASED learning support system for informal CML. The system should be able to support learning that happens in LEARNING GROUPS, it should be possible for the members of learning groups to COMMUNICATE WITH EACH OTHER. The system shall provide services so that the learners can COLLABORATE WITH EACH OTHER. Important to *explore the design space of learning services in the city and STRUCTURE THIS SPACE*. The system shall TAKE INTO ACCOUNT THE *Space* of the learner in order to adapt the system's behaviour according to the *Places* surrounding the learner. Such pro-activeness shall be built over ontological support. The system shall MANAGE AND RECOMMEND LEARNING CONTENT to the learner based on the nature of activity in which the learner is engaged in. The System shall be able to MANAGE INFORMATION ABOUT LEARNER through user profiles.

In the light of the requirements presented here, we will now apply A-MASSEM to these requirements. In FF-CML we represent FABULA system user (i.e. learners) through a special AGORA called UserAGORA (UA). This situation is depicted in Figure **19**, these AGORAs run on the mobile devices of the learner and connect to the application layer AGORAs as registered AGORAs and use the functional capabilities of the system through the services provided by application layer AGORAs.

6.3.2. Understanding the SYSTEM (Active Perspective)

From the requirements different cooperative activities where participants may require *coordination* or *negotiation* support are identified . The process of identification reveals four different types of cooperative activities. These activities include

- o *Authoring Activities*: For allowing the learners to create learning artefacts together
- o *Collaboration Activities:* To allow users to concurrently work over and discuss about learning artefacts
- o *Communication Activities:* To allow the learners to communicate with each other (e.g. texting)
- o *The Group Management Activities:* To manage different learning groups

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[1] The phrases in capital are intended to emphasize the main system's functionality

Other types of activities which may be added at this stage for future extensibility are **application specific activities** that are intended for unforeseen applications that may be supported by FABULA later.

6.3.3.   LOCALIZING System's Dynamics (Active Perspective)

In this step the identified cooperative activities are mapped to AGORAs who will be the providers of coordination and negotiation support. As mentioned earlier the AGORAs identified during this step are called **application level AGORAs**. All the application AGORA identified for FABULA are shown in Figure **19**. The functionality (or behaviour) of AGORAs in the *application level AGORAs* may change (be extended) according to the nature and context of the FABULA application (services). Certain functionalities of AGORAs in the *application AGORA layer* are similar to each other. This is to say that each AGORA in the *application AGORA layer* contains some generic behaviours. Generic parts may include coordination, adaptation, and configuration mechanisms among or within the AGORAs.

Group AGORA: represent sets of learners grouped together in a logical structure. This kind of AGORA takes care of the communication of User Agents (UA) with other UA[s] within the learning group and with other learning groups. We believe that the "*most interesting learning scenarios are those that provide a high degree of situatedness with respect to the social structure and the space where learning experiences take place*" (Canova Calori & Divitini, 2009). Different types of groups can exist in the system, each supporting a particular form of social structure. Maintaining these social structures has different requirements on the strategies of communication, coordination and management within the groups. Five different forms of such structures are relevant to FABULA project (Canova Calori, 2009).

- o Community of Practice
- o Learning ecologies
- o Micorrhizae
- o Smart Mobs
- o Social world as Locales Framework

For supporting each of the above structures, ideally Group AGORAs with different behaviours needs to be created in the system, each specializing in the type of group it supports. These AGORAs ensure the proper representation, management and organization of the social structures.

Space/Place AGORA (SA): People's interactions and social relations are highly local, grounded in and organized around physical *Space*s. Space-AGORA in FABULA represents the current learning *Space* of a learner during a learning activity. A Space-AGORA has an associated *Space* (i.e. geographical area [see chapter 7 for details]) and is mainly responsible for taking care of the learner's movement within its associated *Space*. It is also responsible for creating different Place-AGORAs for each individual

learner. The Space-AGORA is therefore an integral entity of the system that can take certain initiatives, or can behave proactively based on changes in the properties of its associated *Space*.

Application Services AGORA (ASA): The application AGORA takes care of an important aspect of CML. Learning scenarios where learning comes from exploration, interaction and serendipity are characterized by dynamic and emerging learning experiences (Canova Calori, 2009). This implies that the services that are needed might not always be defined a-priori. Though a certain constellation of services might function well at a certain point in time, it might not necessarily be able to evolve. Finding and invoking all the required services might not be possible for the user agents (UAs) or group AGORAs (GAs). The main role of the ASA is to locate and invoke such services, which are relevant for a learning activity. It assists the UA and GA to find and invoke different services of FABULA.

Application Dependent AGORA: Depending on the application at hand, the FABULA system can contain other application dependent AGORAs. Different types of application learning objects (or AGORA) fall into this category.
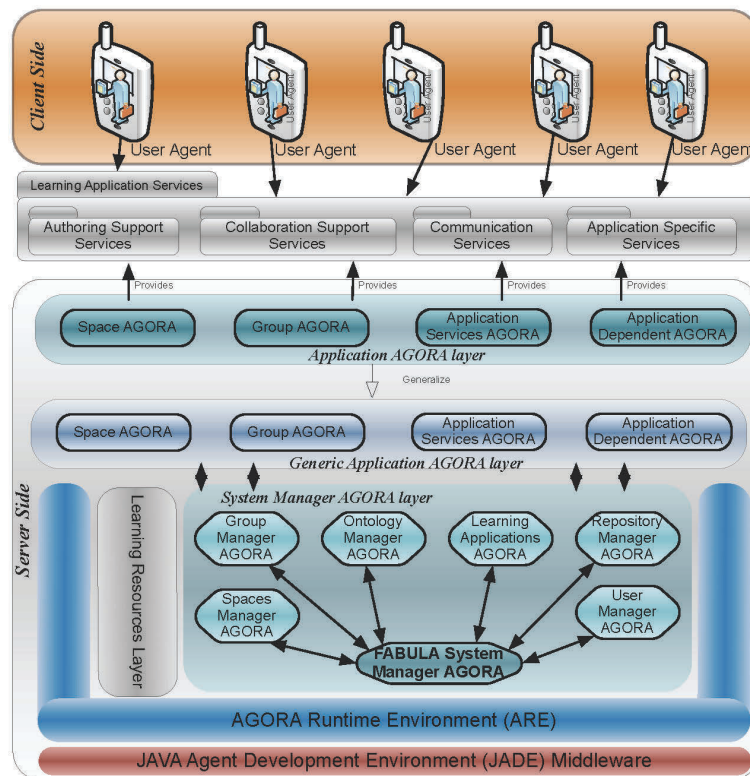

Figure 19: A complete view of F-MAS

6.3.4. Defining The System's DIVERSITY (Passive Perspective)

For each kind of cooperative activity identified during the first step, required services are identified. Depicted in Figure **20**, in FF-CML's *services model* these required services are organized as a layer consisting of four different service categories. In FF-CML the layer that holds these services is called *"Application Specific Learning Services Layer"*.

Authoring Support Services: Include the services that allow users to edit documents (Create, update, delete) and other learning artefacts. The main utility of such services will be during the time when several users are editing a learning artefact. This category of services includes:
- Document Editing Services (Create, update, delete)
- Concurrent Artefacts Editing Management services
- Calendar Management Services

Collaboration Support Services: Consist of complementary services; these services may never play a direct role in the learning. However, they may be invoked by the user in an ad-hoc manner for collaboration. These services are mainly intended to support the performance of shared tasks, to support social networking, allow users to actively participate in the learning activity and make the learning more visible (Canova Calori & Divitini, 2009). These services include:

- Managing social network connections among users
- Recommendations
- Providing Awareness information to the user
- Managing the learning preferences of the learner

Communication Services: These services also consist of complementary services and may never play a direct role in the Learning Application. But, they can be invoked by the user in an ad-hoc manner for communication. Communication services include the following:
- Text messaging
- Picture messaging
- Voice communication

Group Management Services: if a learner decides to learn with a group then these services provide the group management services to the learners. A group mainly combines a number of learners into a logical structure. Services in this categories are mainly those who allow learners to working together.
- Groups management services, taking care of different forms of learning groups
- Managing intergroup relationship
- Providing support for intergroup communication

Application Specific Services: These are the services which may be dynamically added to the system. Since we look at FABULA as a system that could be used in many different learning contexts. Therefore, for each context different services will be

required. Thus, these services will be completely specific to the context of application, and hard to predict. With the addition of such services the system may start to support more learning use-cases or may start to perform better for existing use-cases.

6.3.5. Identifying System Level Service for CO-EVOLUTION (Passive Perspective)

By analyzing the results of the active system perspective and main functional requirements; eight main categories of *system level services* arranged in two different layers were identified for the FABULA system. Depicted in Figure **20**, each layer consists of different categories of services, important categories and their respective services.
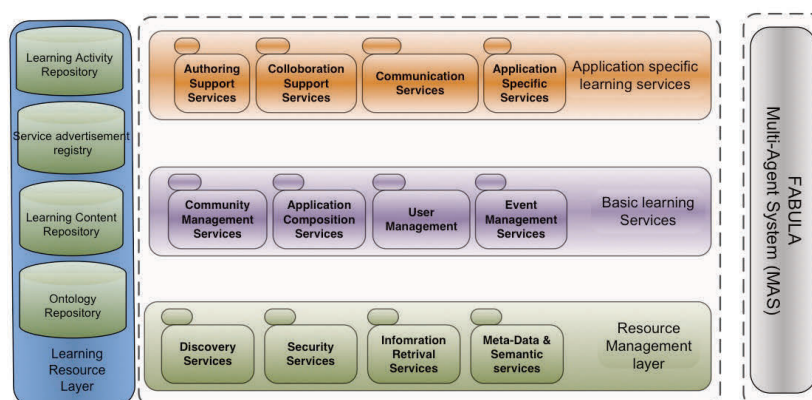
Figure 20: FF-CML's *services model*

Basic Learning Services Layer: Services at this layer are the intermediate level services; they do not directly interact with the user or directly with the learning content. These services use the functionality of the services in the lower layer and support the services in the upper layer at run time. Accessing or providing functionality to/from all the services in other layers is done through clearly defined *Service Access Points (SAP)* (i.e. Service Interface). Thus, maintaining *autonomy* and *heterogeneity* in the system. These services perform the functionalities which are common to many activities in ML. Categories of services in this layers are as follows

o **Community/Group Management Services:** This category of services consists of services related to managing the user groups at the system level, since FABULA is all about collaboration among its users. These services are vital; the sole purpose of these services is to manage different structures and numbers of user groups.
o **Application Composition Services:** Services in this category are responsible for constructing the Learning Applications based on user preferences*.*
o **User Management Services:** Manage the storage, retrieval and search of user profiles.

o *Event Management Services:* We consider FABULA to be an event driven system. Services in this category consist of services which manage different events within FABULA. The main idea to have such an event based system is due to the fact that FABULA is a distributed services based system, thus there is no possibility of integrated programming style (function calls and exception handling). Events provide the necessary abstraction to deal with various kinds of flow primitives as needed by Learning Applications or dependencies among service invocations.

Resource Management Services Layer: This layer provides the most basic system level services for FABULA. These services handle the data that is stored in and accessed from the repositories. Services in this layer are very much static in the system.

o *Discovery services:* Provide information about the other services (basically services in the upper layer) which are available in the system. These services directly operate on the service advertisement repository.
o *Security services:* Category contains all the services related to the security of the system. These services take care of the issues related to the identity and permission management of the user or its agent.
o *Information retrieval services:* This category of services includes the services associated with the content management and retrieval from the content repository. This category include the following services
    o Service for storing, retrieval, organization and searching the content in the content repository
    o Cataloguing Service
    o Content Archival Service
    o Digital rights management Service
    o Services for content reputation and recommendation (social content filtering and collaborative filtering)
o *Meta-data and semantic annotation service:* This category of services works over the ontology repository. The services in this category are required to do semantic reasoning with the concepts of the FABULA-Ontology. The learning content saved in the content repositories can be associated with semantic metadata and the ontology can be queried through these services. Services in this category include:
    • Semantic reasoning service
    • Metadata creator service
    • Terminology service
    • Ontology query service

6.3.6. Identifying KEYSTONE AGORAs (Passive Perspective)

 After identifying the services, the next step is to identify the *system level AGORAs* (also called as *system manager AGORAs*) which would host *system level services*. Depicted in Figure **19** these AGORAs represent a more static part of the FABULA system. Only one instance of these AGORAs exists in the system. Each AGORA in this category takes care of core system functionality. AGORAs in this category are static in

their nature, this is to say that the functionality of these AGORAs will not change for different FABULA applications. This includes the coordination strategies among the AGORAs, supporting Spaces management and accordingly configuring other AGORAs and their capabilities. Thus, they provide a platform for supporting different FABULA applications.

FABULA Manager AGORA (FMA): is the system AGORA which takes care of the overall system functionality. It acts as a supervisor for other manager AGORAs in FABULA.

User Manager* AGORA *(UMA): is the manager AGORA, which takes care of the user AGORAs (UA) in FABULA. It is mainly responsible for managing learner profiles, it also provides services such as learner's authentication, authorization and provides information about the learner to the other system entities.

Groups Manager AGORA (GMA)*:* Although group structures and internal communications of groups are managed by GA at application level, however, at system level overall group management is the responsibility of the *GMA*. This AGORA creates, destroys and maintains the groups in the system, and all GAs are under direct control of the GMA. Besides that, GMA also assists and supports the group related functionalities for the users.

A manager AGORA called the ***Repository Manager AGORA (RMA):*** takes care of the content in a FABULA repositories. Any learning system cannot be considered in isolation of the learning content it provides to its learner. The intelligence and utility of RMA lies in the fact that it understands and manipulates the semantic relationships among the FABULA content. It entertains all the content queries.

Ontology Manager AGORA (OMA): takes care of the FABULA-Ontology. This AGORA is also associated with a repository (i.e. Ontology repository). It manages all the relationships among the FABULA concepts.

Space Manager* AGORA *(SMA): is mainly responsible for understanding all the parameters related to the different learning *Spaces* existing in the city. In our work we consider that there can exist different learning *Space* in the city. This manager AGORA aggregates all the information related to the learning *Spaces* and provides this information to other system entities when needed, so they can adapt the system behaviours according to the learning *Space*. It is also responsible for the management and life cycle activities of application level Space-AGORA (SA).

6.4. Summary

This chapter has presented the architectural foundation for this thesis. Extensions in the AGORA framework that are particularly intended to specialize the conceptual metaphors of AGORA to construct a CML framework considering learner's mobility.

The FF-CML is not like existing frameworks which are too abstract and only specify the services needed in a learning support system. Instead, the FF-CML specify the services which are highly relevant to ML, it also considers a CML support system from the point of view of its dynamic behaviour. Although the FF-CML is only used in context of the FABULA project, however the framework itself is reusable and can be applied elsewhere.

Chapter 7

Articulating AGORA Support for *Space &* *Place* Based Mobile Learning

"An obvious, yet essential, difference is that it starts from the assumption that learners are continually on the move. We learn across Space as we take ideas and learning resources gained in one location and apply or develop them in another. We learn across time, by revisiting knowledge that was gained earlier in a different context, and more broadly, through ideas and strategies gained in early years providing a framework for a lifetime of learning. We move from topic to topic, managing a range of personal learning projects, rather than following a single curriculum. We also move in and out of engagement with technology…" (Sharples et al., 2005)

FF-CML presented in the previous chapter provides an abstract blueprint that discusses the core features of a CML support system in general and FABULA system in particular. However, there is a need to provide fine grain details as to how different locations which exist in city, can be mapped into and managed by a Multi-Agent framework, such as AGORA. As mentioned during Chapter 1 that we have applied the framework of *Place/Space* to render city into a collection of learning *Place*s. The choices made by selecting AGORA and *Place/Space* framework shall be justified through relation argument. Such an argument should reflect the fact that this work is not a random engineering solution to provide support for ML, instead it is placed at the intersection of theory and its application in practice. Having these goals as the central theme, this chapter will discuss our approach of mapping *Place/Space* framework into AGORA. It will also provide an insight as to how the Learning-Experience that is discussed elsewhere as an abstract concept is translated for implementation. In order for this work to be reusable, this chapter will also present different learning patterns for CML. All the concepts discussed in this chapter are further elaborated in the next chapter. **Main aim**—of this chapter is *to provide a detail insight into the mapping process of Place/Space framework into AGORA for providing support for CML.*

7.1. Why *Place*, *Space* and AGORA for CML

We will follow a stepped approach to justify our choices of using a few particular frameworks, while ignoring others. Firstly **Why *Space?*** The core idea of considering *Space* is based on the fact that learning activities are not isolated from the *Space* (i.e. location) where they occur. Therefore, in the case of CML the *Spaces* where the learning occurs should be taken into consideration. In the case of CML *Space* would relate to the physical aspect of locations in the city. We have already discussed several different approaches which have successfully modeled learning *Spaces* to support

learning. City is the key that makes our argument for using *Space* stronger when compared to other applications of ML which model learning *Space* (e.g. in schools, in cafes, in museums etc..). This is because cities mainly consist of different learning *locations*, treating them as ***Spaces*** discussed in theory is very realistic and natural. The exploration of these physical structures of the city commences learning activities (Canova Calori, 2009). Similar approach has been suggested by (Kukulska-Hulme & J. Traxler, 2007) as they suggest to design physical learning *Spaces*, in other words to design buildings for ML.

Secondly Why *Place*? Based on established grounds of applying the notion of *Place* to analyze different activities. We believe that Casey's (Casey, 1993; 1997; 1998) philosophical explanation of *Place* as a meaningful *Space* can be applied to support CML that occurs in a citywide context. Several closely related approaches have demonstrated the usefulness of applying *Place,* for instance see (C. Rossitto, 2009). In this mode of application *Place* would appear as a logical concept that is attached to *Space* and is individually constructed for each individual (i.e. user, learner). From the position of applying *Place* as an overlay of meanings attached to a physical *Space*, our core argument is twofold. Firstly because the concept of *Place* acts as a tool to analyse, argue and implement for CML. Our second reason which is perhaps a more important one, has to do with the notion of experience that occurs in *Place*. The notion of *Place* brings into focus the reciprocal interactions between a physical site and the Learning-Experiences unfolding within it. According to Dierking and others (Dierking, Falk, Rennie, D. Anderson, & Ellenbogen, 2003) learning is a cumulative process consisting of a variety of Learning-Experiences. Constructing on this argument, ML is also a kind of Learning-Experience, as suggested by Sharples and colleague (Sharples et al., 2007) *"ML is the study of how the mobility of learners augmented by personal and public technology can contribute to the process of gaining new [….] experience"*. Current trends in ML's literature and many authors (Canova Calori, C. Rossitto, & Divitini, 2011; G. N. Vavoula et al., 2005; Giasemi N Vavoula & Sharples, 2008) are also in agreement with the view of ML as an experience. Treating ML as experience supports our choice to use the notion of *Place* to render the city into an arena of learning. Since the goal of this work is to support learning about the city by being in the city. From this point of view the learner's experiences of *Places* resulting from visiting *Spaces* in the city are exactly the experiences that we want to support through this work. Thus by using the notion of *Place* we are actually supporting CML. Another important aspect of *Place* that is also relevant for CML is the aspect of movement within and between *Places*. Since CML is heavily focused on mobility of the learner and the mobile device. This aspect brings into light the different types of movements attributed to learners in a citywide context.

Thirdly Why AGORA? AGORA framework matches the notion of *Spaces/Places*; as it is a framework based on the metaphor of *market Place*, and can support the design of Multi-Agent System which correlates with the theory of distributed *Space*s in the city. While the adoption of *Spaces/Places* framework facilitates dividing the city into meaningful learning locations, adoption of AGORA helps transforming the theoretical perspective of CML into a Multi-Agent System to support situated learning activities. Furthermore, AGORA considers open environments where support for social

mechanisms such as coordination, communication and negotiation are desired. Technical supports required by CML are exactly what AGORA is meant to support.

7.2. Types of Mobile Learners and Required Support

This work considers two different types of mobile users that can exist, namely ***mobile learner*** and ***mobile teacher***. Each of them is represented by an AGORA (i.e. Learner-AGORA and Teacher-AGORA) who resides in the mobile device of the user. These AGORAs register with different AGORAs of FF-CML (more specifically F-MAS) and use their functionality. Along with other functionality these AGORAs are responsible for providing the functional support to manage Learning-Experiences which provide input for creating *Places*. A learner can have different learning preferences [discussed in the next chapter], an important learning preference is the **Learning-Goal**. Different learners can have different Learning-Goals. A learner can decide to learn about the *history, culture, social, religious, and sightseeing* aspects of the city. [S]He can also decide if [s]he wants to learn only important traits of a certain aspect of the city in a short period of time or wants to learn in detail without time limitation. From the point of view of managing learner, important requirements imposed by the *Place/Space* framework are the management of different types of **movements** and representation of different aspects of **ML experience** (social, cultural, historical, psychological).

Other important requirements are to manage the **representation of *Space*** and the **emergent nature of the *Place*s**. In other words, there needs to be a mechanism that allows the *Places* to emerge as the learning activities occur in them. It is also important to clarify how the relationships among *Space*s, *Place*s and learners will be managed by the AGORA system. Similar to *Place* the learner's Learning-Experience of *Place* also evolves over time as [s]he visit the same *Place* several time. On one hand *Place*s evolve as the individual perform activities in them, while on the other hand the Learning-Experience of *Place* for each individual also evolves by performing the activities. It is a two way process. This means that for two different individuals, a same *Space* provides two different *Place*s. Thus, the meaning/understanding of *Place* for each individual is personal. The main requirements can be summarized as follows: 1) Management of learner, 2) Representation of *Space*s, 3) Managing the emergent nature of *Place,* and 4) Managing the movement of learners within and between learning *Space*s.

7.3. Mapping *Space*

As it was explained earlier, *Space* is a geographical structure that occupies a physical area (i.e. learning environment). For the purpose of modelling *Space* in this work we consider that a *Space* consists of four geographical coordinates of a piece of land, the interesting objects and the technological services which are available within the area. For example, church, university, museum are three different *Spaces* having some geographical boundaries. The coordinates of a *Space* define the boundaries of a *Space*. Figure **21** depicts the model of *Space*. Along with geographical boundaries, a *Space* also has associated textual descriptions. Interesting *Spaces* are usually not empty, but consist

of different objects. A historical monument, tombstone and similar are examples of objects of interest within a *Space*. We call these objects **Learning-Opportunities** with associated **Learning-Tasks** (multiple choice questions). A "Learning-Opportunity" also occupies certain areas identified by its geographical points within a *Space's* boundary.
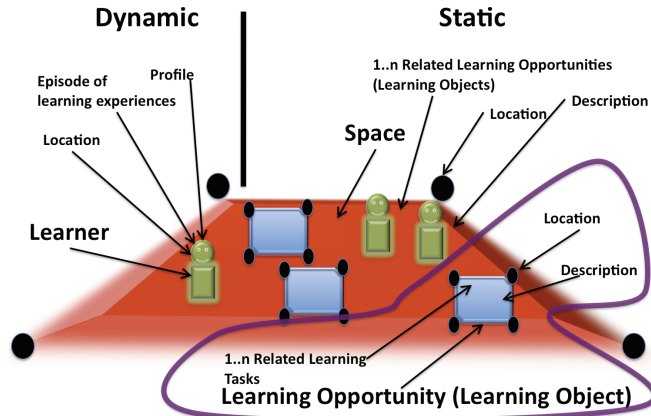
Figure 21: Structure of *Space*

A city consists of several *Spaces* spread over its geographical area. These *Spaces* are placed into different categories based on the kind of activities they are used for. Each *Space* can belong to one or more of these categories. We consider five different categories of *Spaces*: ***Cultural Spaces, Religious Spaces, Social Spaces, Historical Spaces,*** *and* ***Sight seeing Spaces***. Each category includes and represents the related aspect (i.e. cultural, historical, religious and sight seeing) of the city.
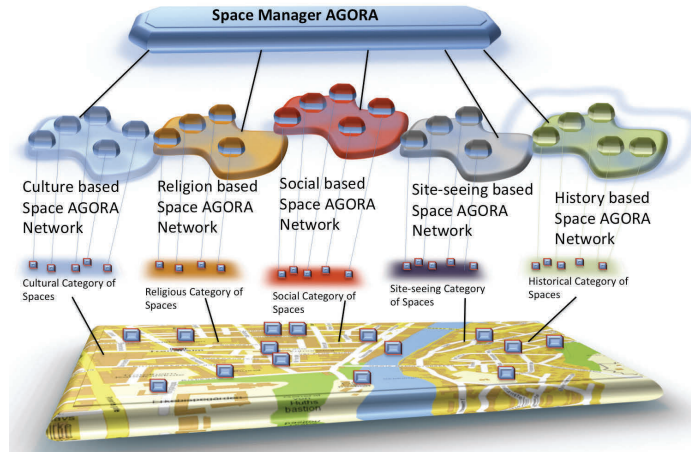
Figure 22: Mapping of AGORAs to categories of *Spaces*

Figure **22** depicts this situation where on the map of a city (Trondheim in our case) several different *Spaces* are depicted as small square boxes. A *Space* can belong to more than one category. For example, a church is obviously a religious *Space*, however, church might also be a historical and sight-seeing *Space*. A "**Space-AGORA**" is associated with each *Space*, where each Space-AGORA represents aspects of its associated *Space*. Space-AGORAs are created and managed by the Space-Manager-AGORA in the system. Space-AGORAs are application-level AGORAs while Space-Manager-AGORA is a system-level AGORA. Space-AGORA acts as a repository of information about its *Space* by keeping the descriptive information about the *Space*. The history of learning activities that have taken place and the comments/tags that the user left about the "Learning-Opportunities" are also kept and managed by Space-AGORA.

Space-AGORAs manages 1) *movement of learner in Space*; 2) *information related to geographical coordinates of a Space* 3) *"Learning Opportunities" in the Space,* and 4) *process of creating and destroying Places over its Space*. When position of a learner is within the boundaries of a *Space*, the learner is considered to be present in the *Space*. A dynamic aspect of *Space* is the movement of learners in and out of *Space*. Therefore, we extend the theoretical conceptualization of *Space* by introducing a modification that the presence/availability of learners is a dynamic aspect of *Space*. Thus, as the learners come and go in a *Space* the amount of available learning resources within *Space* changes dynamically.

Figure 23: Process of *Place* creation
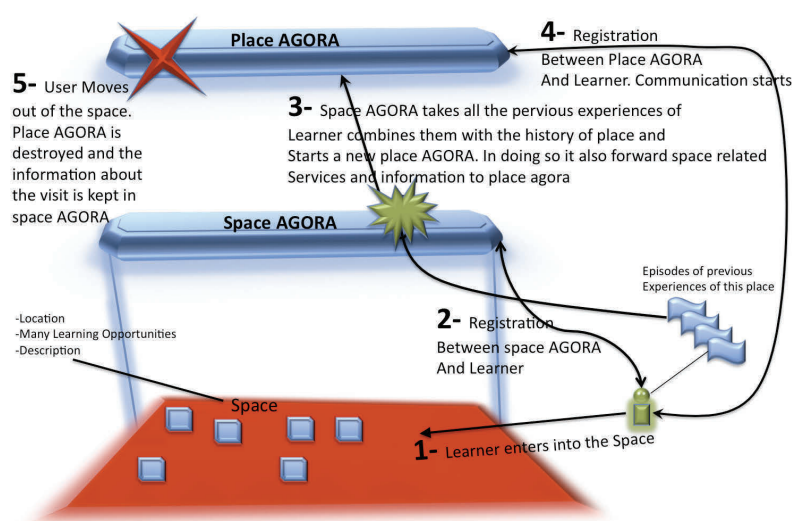
Place Creation and Management of Geographical Coordinates: When a learner enters into the boundaries of a *Space*, the Learner-AGORA registers with the Space-AGORA of that *Space*. As a result of successful registration Space-AGORA creates a new Place-AGORA and hands over the control to Place-AGORA, which then communicates with the Learner-AGORA and sends relevant Learning-Task to be

performed by the learner. The newly created Place-AGORA is the child of Space-AGORA, in this way it is possible for these AGORA to have communication between them. The number of Place-AGORAs for a *Space* at any time is equal to the sum of learners present in the boundaries. As the learner moves from one *Space* to another the Learner-AGORA manages the registration and un-registration for its learner. GPS is used to get the learner's position and WiFi networking capabilities are used for communication between software agents.

Based on the metaphor of *Place* as an event, every time a Place-AGORA is created for the learner an ***episode Learning-Experience*** is also created for him/her. Discussed later, generally an episode of Learning-Experience contains information about the activities of a learner in a *Place*. If a learner visits a *Place* for the first time the episode of Learning-Experience is created form default settings and has no influence on the behaviour of Place-AGORA. However, if a learner has previously visited a *Place* then history of previous episodes of Learning-Experiences is retrieved by Space-AGORA as soon as the Learner-AGORA registers with it. The retrieved episodes of Learning-Experiences when handed over the Place-AGORA influences its behaviours by causing it to send particular Learning-Tasks to the learner. The Place-AGORA is not a permanent AGORA and vanishes as soon as the visit is over. However, just before it disappears, it passes all the information related (mainly Learning-Experience) to the activities of the visitor in that *Place* to its parent AGORA; which in this case is the Space-AGORA. Learning-Experience is then saved in the system for later use. This complete process is depicted in Figure **23**.

Management of Learning Opportunists and Movements of Learner: Another important aspect as described in *Place/Space* framework is to support three different kinds of movements of learners between *Places*. First, kind of movement is when the learner is stationary, but [s]he just moves his/her head, hand etc. We do not consider this movement to be significant enough to be represented in AGORA. The other two kinds of movement are important. The second kind is when the learner moves around within a *Place*. By such movement, a mobile learner might come into the vicinity of a "Learning-Opportunity" such as a historical wall or a monument. For such scenarios we track the geographical position of the learner within a physical boundary of the *Space*, by doing so it is possible for the system to present appropriate "Learning-Tasks" to the learner. Learner-AGORA informs the geographical location of its user to the Place-AGORA. The third and last form of movement is when the learner moves between learning *Place*s. In this case the Space-AGORA for the *Space* from where learner moved out from, informs the Space-AGORA of the *Space* where the learner in entering. In doing so it informs the Space-AGORA about the recent activities of the learner in the previous *Place*. This mechanism allows the system to adopt the new *Place* according to the recent activity of the learner.

7.4. Mapping *Place*

Place is a logical structure which is constructed by combining and reasoning with the previous episodes of Learning-Experiences. However, if there are no previous learning

episodes then the *Place* is created with default configurations. The level of abstraction adopted by *Place/Space* framework does not put any constraint on the size of *Spaces* over which the *Places* are created. From theoretical point of view *Spaces* (consequently *Places*) are elastic concepts and the size of *Space* and *Place* can vary. However, as discussed previously we put a limit on the size of *Space* by defining the geographical boundaries of the *Space*. In order to overcome this limitation and to allow the size of *Places* to grow and shrink. This work considers two different kinds of *Places*; namely **Static-Place** and **Dynamic-Place** that are created based on learner's Learning-Goal. Static-*Places* are limited by the size of *Space* underneath them, while the Dynamic-*Places* can be created over many *Spaces*. Furthermore, centred around the number of learners who visit the *Place*, the concept of *Place* is further subdivided into three different types. If a *Place (static or dynamic)* is created for a single learner then it is called a **Solo Place**. If the *Place* is created for a group of learners then it is called a **Group Place** and if a teacher also accompanies the group then **Group+Teacher Place** is created. Therefore, in total we consider six different types of *Places*, namely **Static Solo, Static Group, Static Group+Teacher, Dynamic Solo, Dynamic Group, Dynamic Group+Teacher.** For each type of *Place* a different type of *Place*-AGORA is created in the system.
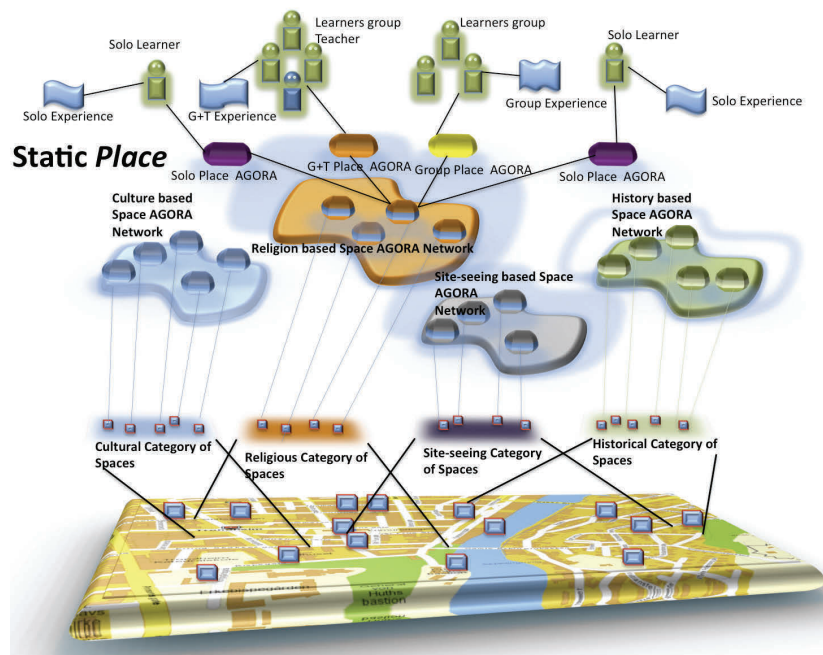
Figure 24: Three different types of Static-*Places* created over same *Space*

7.4.1. Static-*Place*

Based on learner's Learning-Goal (goal = *learn about city*), Static-*Places* are created as learner moves among different *Spaces*. Such *Places* are dependent on the size of learning *Space* for which they are created. Figure **24** shows three different types of *Places* created over a same *Space*. A different type of Place-AGORA is created for different number of learners. A Group-Place-AGORA provides collaboration and communication services to the learners and maintains a higher level of trust among group members, while the Group+Teacher-Place-AGORA allows the teacher to restrict or select the services that are made available to the Learning-Group. The Solo-Place-AGORA provides the learner with the services to support solo learning activities, by helping him/her to visit different "Learning-Opportunities".
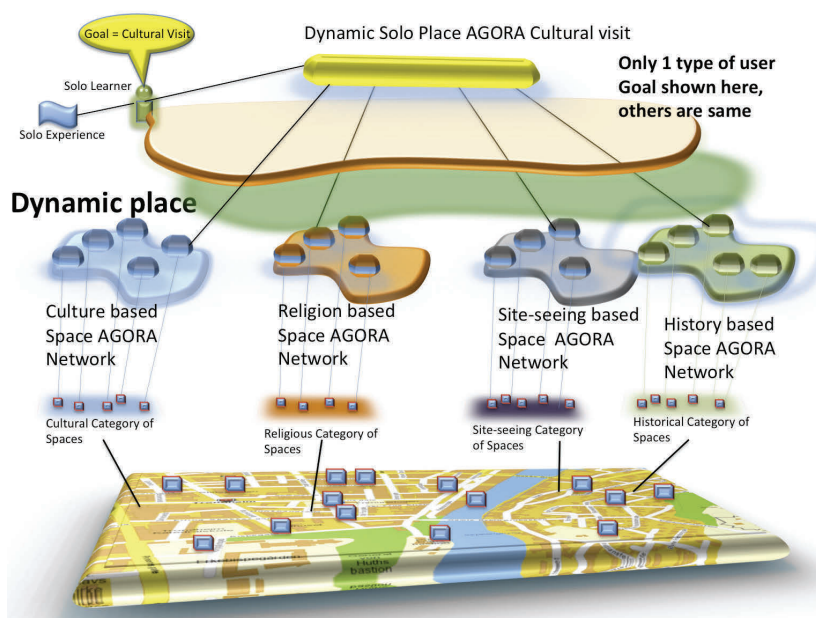
Figure 25: Dynamic-*Place* created over many *Space-AGORAs*

7.4.2. Dynamic-Place

Dynamic-*Places* are created based on the learner's Learning-Goal to visit the city. The mechanism of creation of Dynamic-*Places* follows the following steps: 1) The user selects a goal from five different learning goal *(goal = visit sight-seeing Places, visit religious Places, visit cultural Places, visit historical Places, visit social Places)* for his/her visit to the city; 2) The Space-Manager-AGORA then performs a search in the networks of *Space*-AGORAs to find the *Spaces* that matches Learning-Goal; 3) The AGORAs that match the search criteria are selected and appropriate Dynamic-Place-AGORA is created on top of all Space-AGORAs. Similar to the case of different kinds of Static-Place-AGORAs [see section 7.4.1], three different kinds of Dynamic-Place-

AGORAs can be created, namely Solo-Dynamic-Place-AGORA*, Group-Dynamic-Place-AGORA, and Group+Teacher-Dynamic-Place-AGORA. Apart from normal functionality of Place-AGORA, an important responsibility of Dynamic-Place-AGORAs is to communicate with the *Spaces* underneath them. Figure **25** depicts a situation, where a solo user selects a goal to visit the city to learn the cultural aspects of the city. The size of such *Place* is not limited by the size of *Space* underneath it.

7.5. Supporting User Experience

The mapping framework for understanding experience into a Multi-Agent framework such as AGORA is not a straightforward task. This is because of the fact that not every descriptive and narrative aspect of a theory or framework can be translated to a technical solution. For example, a dialogical process that occurs inside an individual's head cannot be translated to a technical service. Therefore, for the process of mapping theoretical frameworks of experience to AGORA we have divided the attributes into **translatable** and **non-translatable**.

For the mapping purpose, this work considers Casey's and McCarthy's explanation of experience. Both Casey's and McCarthy's explanations of experience are partially overlapping and complementary, but never contradicting. Some aspects, which are missing in one of them, are present in the other. Therefore, we consider combination of both aspects, while treating intersectional aspects as equivalent. Figure **26** shows the intersectional part of Casey's and McCarthy's understanding of experience. *Psychological experience* from Casey's work is closely related to *Sensual, Emotional* threads and *sense making process of reflecting* in McCarthy's framework. Also the *physical experience* from Casey's explanation of experience is related to the *spatio-temporal thread of* McCarthy's framework. We regard five out of six sense-making processes together with compositional thread from McCarthy's framework of experience as non-translatable.
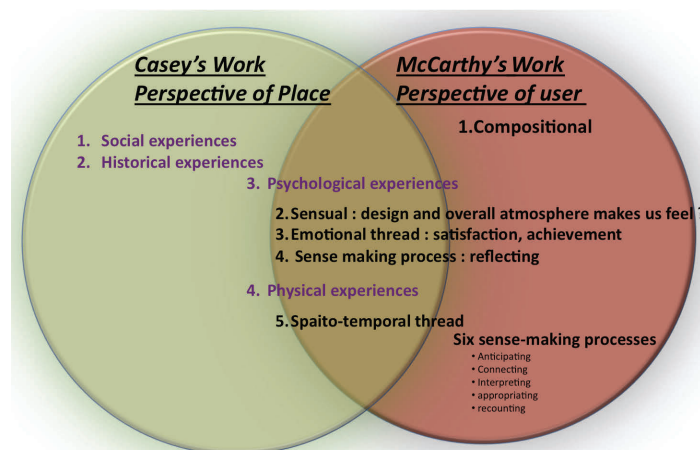

Figure 26: Intersection of Casey's and McCarthy's understanding of experience

As mentioned earlier the outcome of visiting as *Place* is regarded as an episode of Learning-Experience. Every time a learner visits a *Place* an episode of Learning-Experience is constructed as a result of his/her visit to that *Place*. An episode of Learning-Experience consists of the following translatable attributes from the theory:

- o **Social Experience:** considers the number of users who were present in the *Place*. Mainly considers the grouped or solo learning
- o **Historical Experience:** consists of all the previous episodes of Learning-Experiences about a particular *Place* for a learner
- o **Psychological Experience:** consists of overall design impression of the mobile application. This includes user's level (i.e. ranking) of achievement after engaging in ML activity through the use of mobile application and the results of the questions asked from the user to let him/her reflect
- o **Physical Experience:** The time and *Place* when/where the experience occurred. The duration of experience revels its significance. For example, if a learner has spent only 10 minutes visiting a *Place*, while the *Place* requires at least 3 hours for a visit, then the resulting Learning-Experience may not be very significant.

7.6. AGORA Based Patterns of Citywide Mobile Learning

In the citywide context, there are numerous possibilities for different patterns consisting of learners, technological components and physical locations (i.e. *Spaces*). By patterns, we mean to refer to the different ways in which learners are associated with the *Spaces*, with technology that supports learning and among themselves. Envisioning the entire set of such possible patterns, which can exist in the citywide context and designing to support them is not only difficult, but also practically impossible. Therefore, there is a need to condense and generalize all the numerous possible scenarios of CML into core patterns, which can be used as basic building blocks to construct and support more complex CML scenarios.

Such patterns of CML will encapsulate three fundamental aspects. **1)** Firstly, they will provide a general overview of different configurations in which mobile learners are formally organized in the city. This aspect will provide details about the number of learners who are involved in CML. **2)** Secondly they will allow to design supporting technologies for CML. In other words they will bring into focus the number and types of technological components needed to support CML. In the context of this thesis, by technological components we refer to different types of AGORAs that are required to provide technological support. **3)** Thirdly, they will provide a possibility to view different *Spaces* in the city as opportunities where ML occurs. In other words, they will highlight the issues related to the management and organization of *Space*s and *Place*s involved in CML.

Based on this argument we have identified six core patterns for CML. All these patterns consider CML from a very general and generic perspective. The CML patterns discussed in this section are derived from the observation and discussion of the most

common CML scenarios (Canova Calori & Divitini, 2009; Canova Calori et al., 2011) that can exists in the city. These six different patterns are based on the two main features of CML, firstly the **number and type** of learners who are taking part in the process of CML. Secondly, learner's **goal** to be involved in the learning process. The number of learners involved in CML encourages taking a perspective view of CML by considering what different types and number of supporting components are required to provide technological support. The Learning-Goal of the learners enforces the technological support to behave in a certain way as anticipated by the learner, thus putting the learning process directly under the control of the learner. Although in this work we have chosen the AGORA framework to be the most appropriate technology to support discussed patterns of CML. However, other technological frameworks can also be use to provide technical support for the identified patterns. Therefore, these patterns are reusable and generic, thus they can be used in other ways in the systems intending to support CML.

7.6.1. Solo Learner in Static-*Places* (SLS)

This is the first of six CML learning patterns identified during this work. Figure **27** depicts the SLS pattern that focuses on a mobile learner who goes alone to the city to learn about it. Furthermore, such learner chooses to a learn about the city (goal = *learn about city*) without specifying interest in any particular aspect of the city.
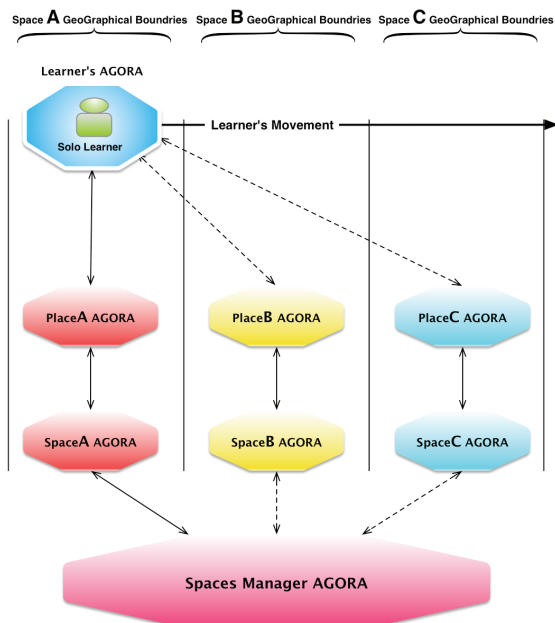

Figure 27: Solo learner in Static-*Place* pattern

In this case the learner's movement in the city controls the system behaviour and the *Places* creation process. Shown in the Figure **27** as the learner moves from one *Space* to

another, a new *Place* is created for him/her. The *Place* created for the learner is bounded by the size of the underling *Space*, in other words mainly the Static-*Places* are created for the learner. As the learner moves from one *Space* to another the Static-*Place* created for him vanishes and a new *Place* is created for him/her in the new *Space* where [s]he enters. It is the simplest case when movement of a single learner is considered to be the central aspect that guides the system's behaviours towards the learner.

The main AGORAs involved in this pattern are Learner-AGORA, Space-AGORA, Solo-Place-AGORA and Space-Manager-AGORA. The Learner-AGORA manages the registration with AGORAs of the *Spaces* where the learner is present. Based on the registration static-Place-AGORAs are created based on the movement of the learner. Responsibility of Space-Manager-AGORA, as discussed earlier is to manager all the Space-AGORAs present in the system.

7.6.2. **Group of Learners in Static-*Places* (GLS)**

As the name suggests this pattern considers Learning-Group instead of a solo learner. Through the different use case scenarios (Canova Calori & Divitini, 2009; Canova Calori et al., 2011) it can be inferred that CML occurs when a learner learns alone or when many learners learn together in the group. As depicted in Figure **28** two different groups of learners are involved in the learning activity.
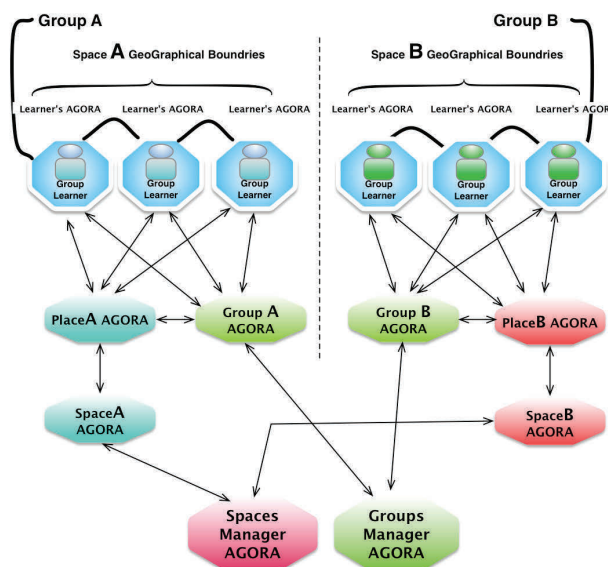
Figure 28: Group of learner in Static-*Place* pattern

This pattern is specifically targeted to provide support for group based CML. Different groups of learners with a Learning-Goal to learn about the city can go to the city to learn about it. In comparison to the previous pattern, the main difference is the consideration for a group of learners. Based on the movement of group of learners in the

city, Group-Place-AGORA is created for the groups. The presence of Group-AGORA allows the group members to cooperate and collaborate with each other and provides the group management functionality. Six different types of AGORAs are needed to provide the complete technical support for this pattern of CML. Namely the Space-Manager-AGORA, Groups-Manager-AGORA, Group-AGORA, Space-AGORA, Group-Place-AGORA, and Learner-AGORA. In this case instead of managing only one learner the Group-Place-AGORA provides support for the whole group. The Spaces-Manager-AGORA and Groups-Manager-AGORA of FF-CML manages the Space-AGORAs and Groups-AGORAs respectively.

7.6.3. Group of Learners With Teacher in Static-*Places* (GLTS)

The last CML learning pattern dealing with Static-*Places* is GLTS. This pattern also takes into account the movement of the learning groups together with teacher among different *Spaces* in the city, the movement of the groups provide input for *Place* creation. It is an extension of the previous pattern. Instead of only considering the group of mobile learners, this pattern also considers teacher as a part of the learning group.
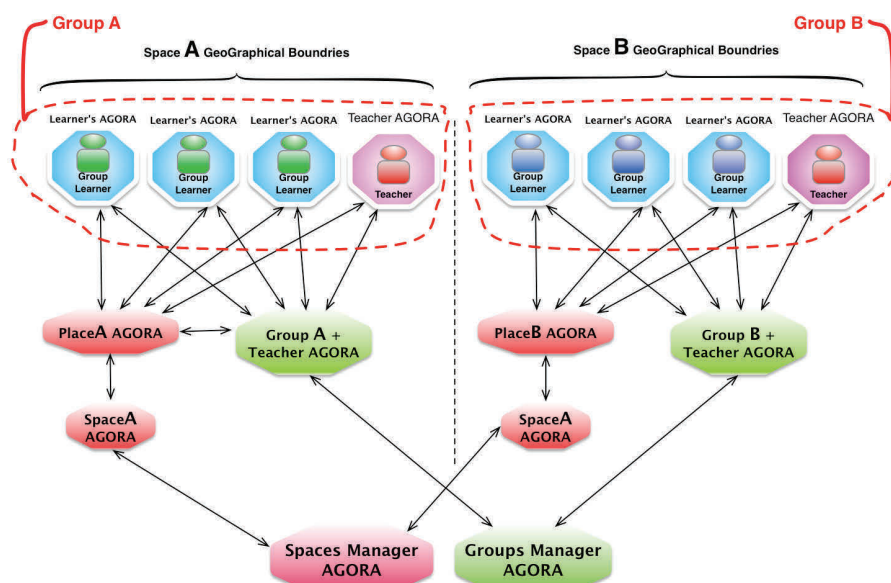
Figure 29: Group of learners + teacher in Static-*Place* pattern

It particularly focuses on the possibilities that arise when a teacher is also part of the learning activity. Apart from the functional components previously discussed, this pattern consists of two special AGORA called Group+Teacher-Place-AGORA and the Teacher-AGORA. Group+Teacher-Place-AGORA is a specialized form of Group-AGORA. Both of theses AGORA impose structure over the unstructured CML learning activities.

7.6.4. Solo Learner in Dynamic-*Places* (SLD)

The CML learning patterns that are based on Static-*Places* provide a way for the learner(s) to learn about different *Spaces* in the city as they move through the city. However, learner(s) might not always want to learn everything about the city and its *Spaces*; instead the learner(s) may only be interested to know a particular aspect of the city. This is where the patterns consisting of Dynamic-*Places* are needed. SLD as depicted in Figure **30** is the first of such patterns, which takes into account the learner's goals to learn about a particular aspect of the city *(goal = visit sight-seeing Places, visit religious Places, visit cultural Places, visit historical Places, visit social Places)*.

In terms of number of learners involved SLD is identical to the SLS, however the way the *Spaces* and *Places* are managed by the system is completely different. For instance, if the learner decides to learn about the *historical* aspects of the city. Then the system dynamically selects only the relevant *Spaces* (represented by Space-AGORAs) in the city, which have more historical value compared to other *Space*s that might not be very relevant. A Solo-Dynamic-Place-AGORA is created over all the selected *Space-AGORAs*.

Figure **30** depicts the complete view of the SLD pattern, where three different *Spaces* (represented by three *Space*-AGORAs) are selected and a Solo-Dynamic-Place-AGORA is created over them. The creation of such an AGORA network happens by a three-stepped process. 1) The Learner-AGORA (representing learner) registers with the *Space*-Manager-AGORA and informs it about the learning goal of the learner. 2) Based on the learning goal the Space-Manager-AGORA performs the search in the AGORA network and selects the relevant *Space*-AGORAs (i.e. *Spaces*) that matches the learning goal. 3) Lastly a Solo-Dynamic-Place-AGORA is created over all the selected *Space*-AGORAs, which encapsulates the features of all the selected *Spaces* over which it is created.
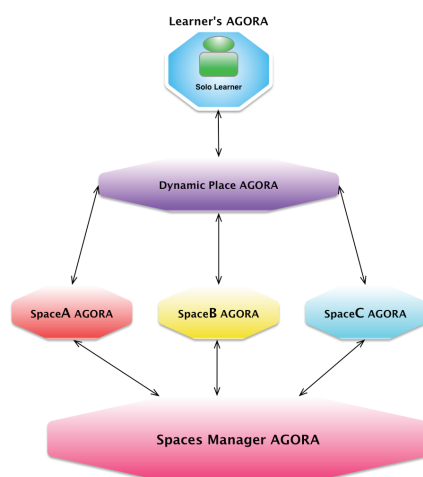
Figure 30: Solo learner in Dynamic-*Place* pattern

7.6.5. **Group of Learners in Dynamic-*Places* (GLD)**

Similar to the GLS CML pattern, GLD is a CML learning pattern that considers the goal directed CML that happens in the groups. As depicted in Figure **31** several learning groups may decide to learn about a particular aspect of the city. GLD pattern consists of the different type of AGORAs needed to support such form of learning. This pattern is intended to capture a situation where a group consisting of several learners, each represented by its Learner-AGORA decides to pursue a specific learning goal. As mentioned earlier a group may decide to learn about the ***historical, social, cultural, religious and sightseeing*** aspects of the city. Shown in Figure **31**, based on the Learning-Goal of each learning group, appropriate *Spaces* are selected by the Space-Manager-AGORA. A Dynamic-*Place* is created as an overlay above all the *Spaces*; this Place is represented by the Group-Dynamic-Place-AGORA. The Group-AGORA and the Group-Dynamic-Place-AGORA provide the group management and *Place* related services to the members of each learning group.
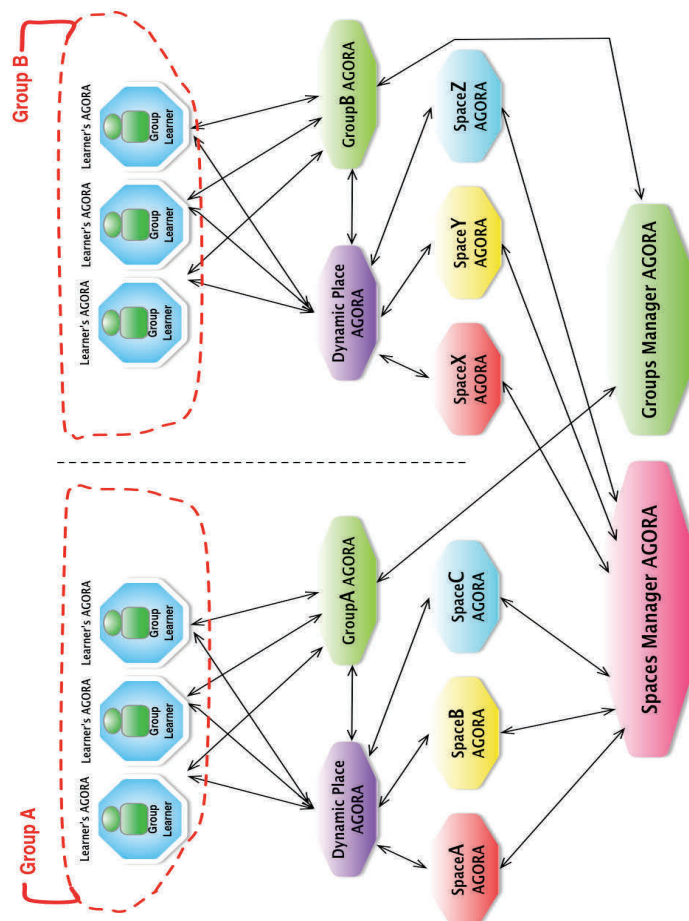
Figure 31: Group of learners in Dynamic-*Place* pattern

7.6.6. Group of Learners With Teacher in Dynamic-*Places* (GLTD)

The last of six patterns for CML is the GLTD. This pattern is an extended form of GLD pattern and considers that a teacher along with different learners can be a part of learning groups. Similar to the patterns discussed in the previous two sections, which support learning process based on the learner's Learning-Goal. This pattern also considers Learning-Goal of the learners as the main input for *Place* creation. The main difference is the presence of the teacher that is represented by the Teacher-AGORA. Teacher-AGORA enforces rules and structure of learning activities performed by the group members. Shown in Figure **32** are two different Group+Teacher-Dynamic-Place-AGORA created for learning groups each managed by a teacher.
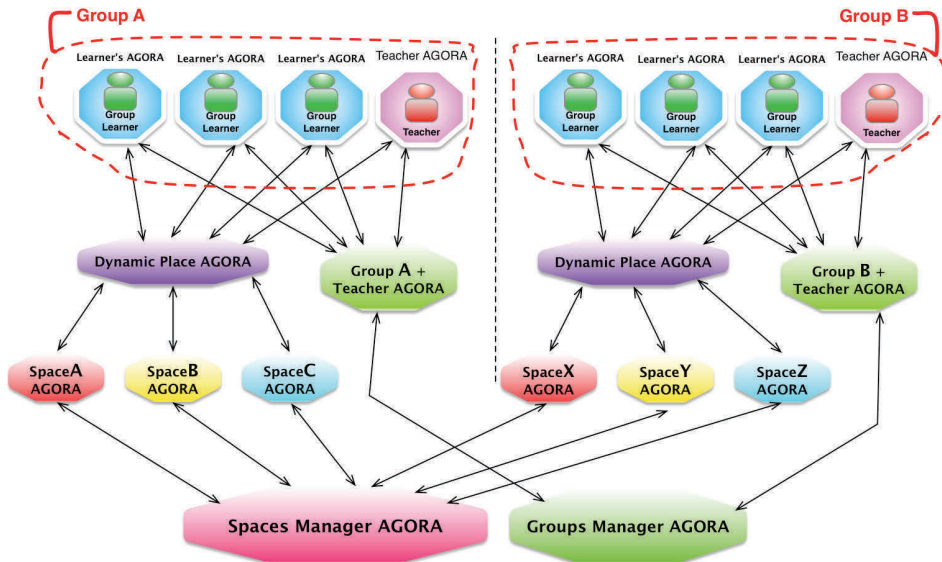
Figure 32: Group of learner + teacher in Dynamic-*Place* pattern

7.7. Summary

In this chapter we have presented the approach for mapping the theoretical concepts of *Space/Place* and Learning-Experience into the AGORA Multi-Agent framework. Also discussed in this chapter are different types of *Places* that are relevant for CML. Furthermore, this chapter has presented re-usable CML patterns. The results presented in this chapter bridge the gap between theories and their practical implementation in terms of technology. Our approach not only considers the physical issues of geographical area of the city, but also the issues of experience. The detailed translations of theoretical concepts are implementation ready and can be implemented to support CML. The main benefit achieved though such mapping, is the fact that the established,

7.7 Summary

proven and useful theoretical concepts of making a differentiation between *Space* and *Place* can be used in practice for CML. The reusable patterns identified in this chapter, can be used elsewhere without any changes to provide a solid ground of understanding over which more complex CML scenarios can be created and supported. The understanding developed during this chapter provides the foundations for the implementation of CML system.

Chapter 8

Design and Implementation of Ontology & *Places/Spaces* Based Mobile Learning System

Implementing wireless and mobile education [...] must address [...] social, cultural, and organizational factors. They can be formal and explicit, or informal and tacit, and can vary enormously [....] different disciplines have their own specific cultures and concerns, often strongly influenced by professional practice in the "outside world" – especially in the case of part-time provision and distance learning. Because most work in mobile learning is still in the pilot or trial phase, any explorations of wider [...] issues are still tentative [...] but it points to considerable hurdles with infrastructure and support (John Traxler, 2009).

Discussion in the previous chapters presented details of a CML framework (i.e. FF-CML) consisting of services and software agents. Furthermore, previous chapters also presented an in-depth mapping of theoretical concepts, namely the Learning-Experience and *Space/Place* framework into AGORA framework. Extending on those grounds, the first part of this chapter will present our *approach for creating a CML ontology* and the ontology itself. This part will elaborate and present the implementation issues of CML ontology (i.e. knowledge model) that combines all the previously presented CML concepts into a coherent structure comprised of different concepts and the relationships that holds the ontological concepts together. The rest of the chapter will mainly focus and discuss the implementation details of FF-CML. Generally speaking overall implementation work can be divided into three main subparts. The first part is dedicated to the implement the *extended AGORA framework* [see section 6.1]. During the second part of implementation work, FF-CML is implemented over the AGORA framework. Implementation of FF-CML focused on the realization of services and different AGORAs discussed in section 6.3. Collectively the implementation of services and different AGORAs result in a software artefact that acts as FABULA-Server-Side machinery (also called FABULA-Server) for providing different services to the mobile learners. The third and last part of FF-CML's implementation is dedicated to the implementation of FABULA-Mobile-Client software that resides on the mobile devices of the learner and communicate with FABULA-Server to consume different services for supporting CML. **Main aim** — of this chapter is twofold, firstly to ***present an ontology for Place/Space based CML and its implementation.*** Secondly, this chapter will ***discuss the implementation of FF-CML.***

8.1. Design Model of Ontology

In order to construct the ontology for CML that can be used in the FABULA project, we have followed an iterative approach. Before, implementing and creating a final ontology several meta-models of ontology were created and refined to create a comprehensive model of ontology that can describe each aspect of CML in considerable detail. During each iteration, several different concepts related to CML came under consideration as possible candidates to be part of the complete ontology for FABULA. Mainly the concepts which were needed to describe *users*, *learning context*, *locations in the city*, *types of learning activities & tasks, learning experience, different aspects of city* (social, cultural, historical, etc.) and *different types of learning groups* were considered. Each iteration resulted in a meta-model that further refined the previous one, by adding and/or removing different concepts and relationships. Central to each iteration were two main goals which guided the process of enriching the meta-model. The first goal was to create a meta-model that contains the concept, which can be used by the system to perform smart operations for example recommendations, for instance see (Parmiggiani, 2010). The second goal was to include those concepts and relationships, which can meaningfully describe the theoretical notions such as *Space/Place*, Learning-Experience and the relevant details surrounding them. Earlier work pursuing this goal was done during (Donate, 2010) and (Parmiggiani, 2010). The ultimate target was to come up with a meta-model of ontology that can significantly cover the most relevant aspects of CML, while at the same time it was important not to over populate the model with irrelevant concepts and relationships which have no or very little role to play in the system intending to support CML in context of FABULA project.

As a result of the above described iterative approach, three fundamental aspects of CML and their related concepts along with the relationships among them were identified. Namely, **FABULA** *User Model* (FUM), **Learning-Experience** and *Places & Spaces*. Another aspect that is partially important, yet not a central aspect of the ontology is **Learning Groups**. Figure **33** depicts the model that resulted after several iterations and refinements. Due to figure size, **Learning Group** related concepts and a detailed view of properties of few concepts are not shown in Figure **33**. The ontology that resulted as an outcome of implementing this model transformed the narrative theoretical descriptions into a working artefact that is applied in practice to support CML. An important part of this ontology is FUM, which is inspired by GUMO (Heckmann et al., 2005; Schwartz et al., 2005). FUM considers both static and dynamic information (i.e. knowledge) about the learner. The static information mainly consists of information such as demographic, contact and record of previous Learning-Experience. While the dynamic information of the user model consists of information related to the mobility and emergent learning experience of a learner in the city. The second part of the ontology is related to formal ***representation of Casey's notion of Place/Space*** that was adopted and applied to structure and organize different locations in the city to support CML. The third and final important part of the ontology is the ***explicitly represented Learning-Experience***. The properties, attributes and classes extracted from theoretical accounts are divided into translatable and non-translatable categories [as discussed during section 7.5].
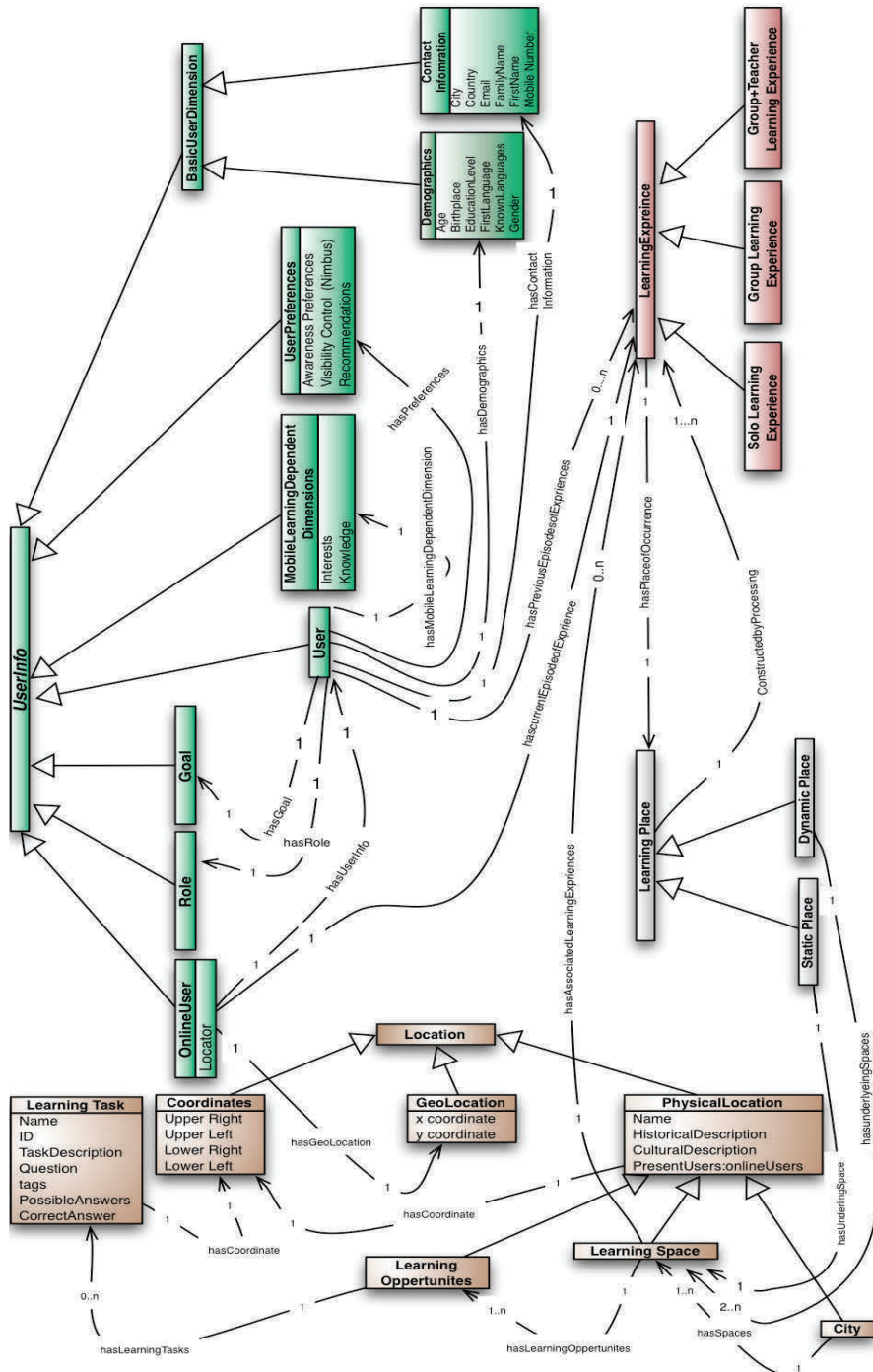
8.1 Design Model of Ontology

Figure 33: Important concepts of FABULA system ontology

Combining two different theoretical fragments and adopting a well established user model to create a ready to use ontology for CML is the main novelty. The resultant ontology can be reused in other project attempting to support some other form of CML.

8.2. Implementation of Ontology

For the purpose of implementation of the ontology, Web Ontology Language (OWL) (McGuinness & Harmelen, 2004) is used. We used an ontology modelling tool called protégé for creating the ontology. The complete ontology is tightly integrated with JADE and it is used with AGORA based F-MAS. Along with others, all the three main aspects of the meta-model are implemented in the ontology. Figure **34** presents the complete implemented view of FABULA-Ontology.

8.2.1. Implementation of FUM in Ontology

As discussed earlier, FUM for CML is inspired by GUMO and is the first of three central parts of our Ontology. GUMO provides a general-purpose user model that is very detailed consisting of more than 1000 concepts. However, not all the concepts of GUMO are useable for CML. Therefore, our approach only considers the concepts which are relevant for CML. Generally speaking, we have divided the FUM into two main parts. The first part deals with the static information about the user; the second part deals with the dynamic information and is related to the aspect of user mobility. Figure **34** shows the main concepts (i.e. classes) that we have included in FUM. MobileLearningDependentDimensions and BasicUserDimensions are the concepts that hold all the static information about the user. Demographics has properties such as *age, gender, education level, and known languages*. ContactInformation has basic properties allowing capture of some basic contact information such as *email, Facebook ID* etc. While the MobileLearningDependentDimensions has properties such as *interests*, *knowledge about Places* and *ranking*. The rationale behind keeping such basic information about the user is to use it for the purpose of recommendations.

Dynamic part of FUM consists of four main concepts, namely Goal, OnlineUser, Role and UserPreferences. The Goal concept allows the mobile learner (i.e. user) to choose his/her goal of CML. [S]He can decide to *learn about city, visit sight-seeing Places, visit religious Places, visit cultural Places, visit historical Places or visit social Places*. By selecting the goal of CML, the control of learning resides with the learner (i.e. user) and [s]he can decide to change the Learning-Goal at anytime. The OnlineUser concept has properties which allow capturing current *position, locator,* and state of *Learning-Experience* of the learner. Availability of this information allows the system to perform location and context aware operations for the user. Role concept has properties that allow the learner to decide to act either as *learner* or as *teacher*. Finally the UserPreference concept has following properties, *AwarenessPreferences, PreferedLearningStyle, RecommendationsPreferences* and *VisibilityPreferences*. Through *AwarenessPreferences* a learner can increase or decrease the amount of awareness information sent to his/her mobile device by the system. Through

8.2 Implementation of Ontology

RecommendationsPreferences a learner can decide to be recommended about different things such as other Learners, *Places*, and LearingActivities. A learner can decide to *learn solo*, in *group* or *group with teacher* by changing the value of properties provided by *PreferedLearningStyle* property. Finally a learner can also decide if [s]he wants to be visible to other mobile learners in the city.
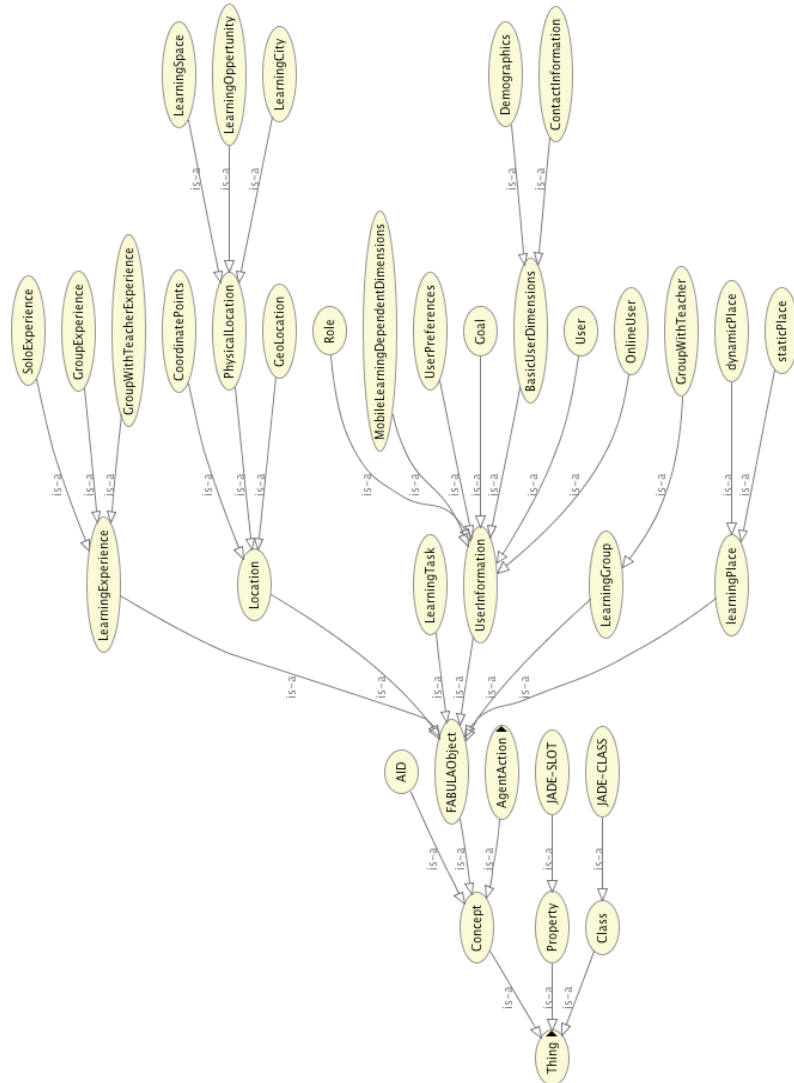
Figure 34: Complete implemented view of FABULA-Ontology

8.2.2. Implementation of *Places/Spaces* in Ontology

The next main part of ontology is the formal representations of theoretical concepts of *Space* and *Place*. As discussed earlier in theoretical terms *Space* is a static concept that is mainly related to the physical aspects of a location. Discussed during section 5.2, a city is considered to consist of several *Space*s; a *Space* has certain boundaries defined by the four different coordinate points. There may be several Learning Opportunities present inside the boundaries of *Space*. These Learning Opportunities also have associated geographical boundaries and different possible Learning Tasks associated with them. When a learner performs Learning Tasks, it is assumed that [s]he learns something about the city, which [s]he was not aware of before. On the other hand, *Place* is a logical structure which is constructed from the combination of previous Learning-Experiences of individual learner. Also discussed earlier, theoretically *Space* is elastic and can be stretched or shrunk as needed. However, this is not possible in practice and cannot be implemented. To overcome this limitation of theory we consider two different types of *Places*. The first type of *Place* is *Static-Place* and the second type is the Dynamic-*Place*. Static-*Place* is constructed over single *Space* and thus is constrained by the geographical boundaries of the underlying *Space*, while Dynamic-*Place* can be constructed dynamically over several *Spaces*.

Figure **34** depicts the concepts representing *Space* and *Place* in ontology. Location is the super concept representing *Space*. LearningCity, LearningSpace and LearningOppoertunity are different types of PhyicalLocation. Each kind of *Space* has properties that allow associating cultural, historical, religious, social, and sightseeing descriptions along with ranking. These descriptions and rankings are used by the system when constructing a Dynamic-Place for the learner. Other properties of *Spaces* allow learners to attach tags and leave comments about *Place*. Also shown in the Figure **34** are two different kinds of *Places* which can be constructed over *Space*: *Static-Place* and *Dynamic-Place*. Parameters that characterizes the type of *Place* to be either dynamic or static is the learner's Learning-Goal. In case a learner decides to learn about a particular aspect of the city, the system then chooses particular *Spaces* within the city that matches the Learning-Goal of the learner. A Dynamic-Place is then constructed for the learner over chosen *Spaces*.

8.2.3. Implementation Learning-Experience in Ontology

The last and final important part of our ontology deals with the representation of Learning-Experience. Every time a leaner visits a *Space* an episode of Learning-Experience is created. This consideration is based on the metaphor of *Place* as an event as described by Casey. Presented earlier are two different theoretical frameworks that can be used to understand experience. Therefore, we adopt an approach that takes into account the intersection of both frameworks.

All the translatable aspects are integrated as properties of three different kind of learning experiences as shown in Figure **34 SoloExperience** occurs when the learner's preferred style of learning is Solo, the GroupExperience occurs when the learning happens in a group, and the GroupWithTeaherExperience occurs when the group of learner is supported by the teacher. Apart from the translation of theoretical concepts to form CML experience. We also add into experience the trace of learner's movement in the city along with the Learning-Tasks that users perform at different locations (i.e. positions) in the city. Based on this information the Place created for the learner adapts for the subsequent visit.

8.2.4. Other Parts of Ontology

Other parts of the ontology are Learning-Groups, *agent actions* and predicates, which are not discussed here. F-MAS makes full use of the concept and properties presented in this ontology, which allows interoperation of agent actions within our system and between FABULA-Server and FABULA-Mobile-Client developed for CML.

8.3. Implementation of *Places/Spaces* Based ML Support

Briefly highlighted during the introduction of this chapter, that besides ontology the remaining implementation work done during this thesis can be divided into three main parts, namely implementation of AGORA framework, FABULA-Server and FABULA-Mobile-Client. We will now provide details of the implementation work. It would not be possible to go into every nitty-gritty detail of the implementation, however an attempt is made to present all the interesting details. All the implementation work is mainly done through the use of JAVA programming language together with SQL to manage the data in the system, while XML is partially used for creating system interfaces. Since this work mainly considers agent oriented software development as a central way to provide support for CML and because agent oriented software development is very different from Object Oriented Software development, it was important to select an agent development tool, even before the implementation work would start.

In the sub-sections to come, we will discuss the agent development tool, which we have chosen for the implementation. We will also provide main reasons for choosing that platform. Subsequently, we will then discuss the implementation of AGORA framework, FABULA-Server and FABULA-Mobile-Client which are constructed over the agent platform.

8.3.1. Choice of Agent Tool for Implementation

The main goal of any agent tool is provide programming support for creating Multi-Agent Systems. Different agent development tools were discussed previously during section 4.1.4. Also mentioned in section 4.1.4, is that the programmer's choice of any

agent development tool is contextual to the application. In this work, along with other requirements, the main requirements were to

- o **Be Open Source:** because AGORA framework will be programmed using this tool, therefore it is important that the source code of the tool is available in case extensions and changes are to be introduced in the tool's code
- o **Support Mobility:** the most important requirement of the programming tool is its support mobility. Since mobility of learning device and the mobile learner is central to this work, therefore is it of utmost importance that the selected tool support mobility.
- o **Run on Resource Limited Devices:** mobile devices used for CML are capable and powerful. However, there are still limitations in terms of available system resources. Therefore, it is important that the programming tool is capable of delivering a system that can function with limited resources.
- o **Support SL Agent Communication Language:** SL is the content language for agent communication in AGORA. Certain support shall be pre-built in the programming tool to support SL based agent communication.

For the purpose of experimenting and demonstrating the work presented in this thesis, JADE is selected as a main development tool for creating AGORA based MAS for supporting CML. The reasons for choosing JADE are as follows: **Supports Mobility:** three different version of JADE are available. The standard version runs on a normal computer and complete JAVA programming language can be used to create agents. While the other two LEAP versions (Caire & Pieri, 2008) are particularly tailored to run on mobile devices with J2ME support or higher and allows to use a limited version of JAVA language to programme agents. The standard version of JADE can also be ported to Android based mobile device using a plug-in (Gotta et al., 2008) specially created for this purpose. This feature of JADE is perhaps the most important feature when considered form the point of view of this work. **Open Source:** as discussed earlier during section 4.1.4, JADE is completely open source and is free to use. Developers are free to make changes in the code and create add-ons for JADE. As a result there are a lot of developers who can help and advise during the development process. Since we programmed AGORA framework, this feature of JADE played a big role in selecting JADE. JADE also supports SL language and is widely used in research. Through its use it becomes relatively easy to discuss and talk with other researchers about it. The other issues which we considered important while selecting JADE were its support for distribution, good documentation, huge developer community, support for debugging, ease of use, previous experience, integration with other tools such as Protégé, Jess etc.

8.3.2. Implementation of AGORA framework

Constructed over JADE, the AGORA framework is used as a middleware over which CML related functionality for the rest of the system is built. From an abstract point of view AGORA as a framework provides conceptual understanding as to how the system components (i.e. AGORAs) should be organized to conduct a cooperative activity and what different forms of communication will be employed by the system components. In

other words, AGORA is a very general and generic framework that can be used for several different purposes in a number of situations. Due to this fact several different implementations of AGORA have been done by others to take advantage of its potential and benefit from its unique way of organizing system components and their communication. Therefore, during this PhD work, in order to unleash the power of AGORA framework for supporting CML, yet another implementation of AGORAs is undertaken.

We have already argued briefly in section 7.1, that the AGORA framework matches the *Place/Space* framework whose application is very relevant for CML. In addition to that, the main goal of this implementation was to further specialize AGORA framework for CML support. To this end we considered the mapping of *Space/Place* central to AGORA. As could be noticed during the discussion in section 6.1 that two different types of AGORA graphs matches the idea of different networks of *Spaces* in the city. Furthermore, the concept of AGORA-Node is tailored and added into the framework so that different information related to *Spaces* in the city can be kept in it. The search mechanisms added into the AGORA framework allow one to search learning *Spaces* in the city when Dynamic-*Place* is to be constructed based on Learning-Goal.

Figure 35: Complete view of implemented AGORA-Ontology

With the help of Figure **36**, we will now highlight some of the main features of AGORA framework. As can be noticed in Figure **36**, when AGORA framework starts, it starts over JADE and different AGORAs appear in the JADE. Integrated into AGORA is small AGORA-Ontology that acts as a backbone of AGORA framework. This ontology is implemented using protégé frames (Sachs, 2006). AGORA-Ontology was abstractly depicted in Figure **14** and Figure **15**; in this section Figure **35** depicts the complete view of AGORA-Ontology. This ontology is used by the agents of AGORA framework and shall also be supported by external agents intending to communicate with AGORA framework's agents. Agent actions that were not relevant for CML were not implemented, since they were not needed for CML support.

It is Important to underline AGORA's way of organizing the system components. It is assumed that a system built using AGORA framework uses the core functionality of pre-built AGORAs, at the same time it is also possible to create more sophisticated

AGORAs specialized for particular application, examples of such AGORAs are presented in F-MAS. The core functionally which is built into each AGORA consists of different communication protocols, services, management of data in AGORA-Node and management of AGORA parent-child graph. The protocols such as registration, de-registration with other AGORAs and agents is pre-programmed and are inherited by each AGORA when it is created by extending the base AGORA class. In Figure **35** prebuilt protocols of AGORA appear as *agent actions*, these agent actions can be invoked by other agents as services. The upper left corner of Figure **36** shows different services that are supported by an AGORA.
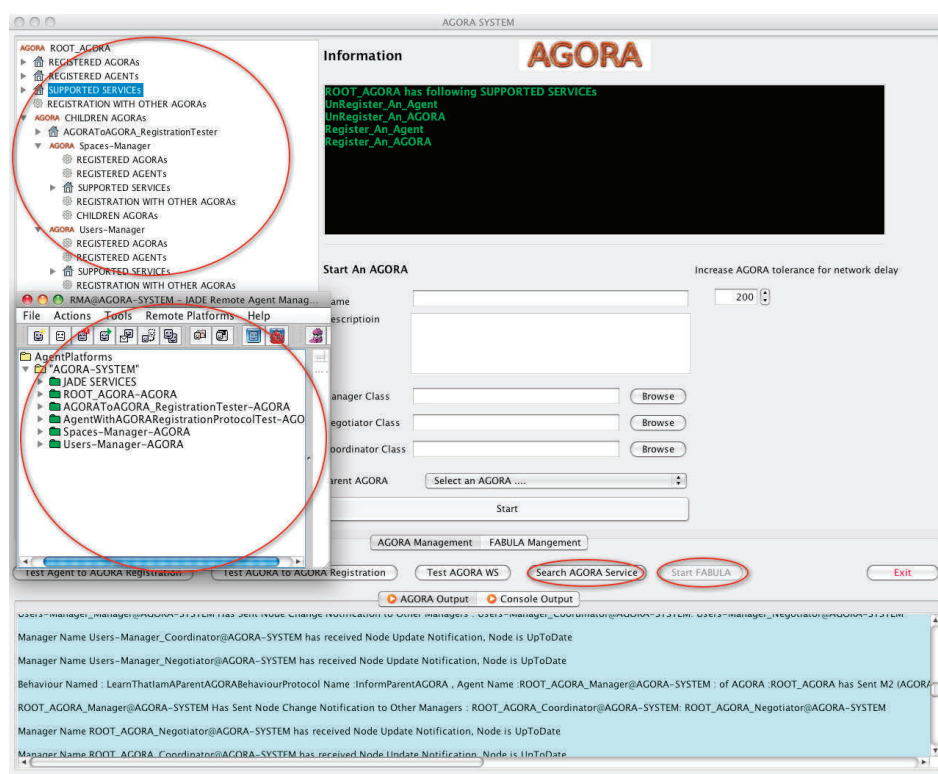
Figure 36: View of running AGORA framework over JADE

It is not possible to discuss the details of all the protocols that are implemented; therefore, we will only discuss one protocol. Our intention is to highlight the rich communication language support that is integrated into each AGORA. Thanks to the AGORA-Ontology it is possible for AGORA agents to communicate using SL as the content of their communication messages. This feature is very useful when the domain of AGORA application is complex, where simple String based parsing of message content is not practical and feasible.
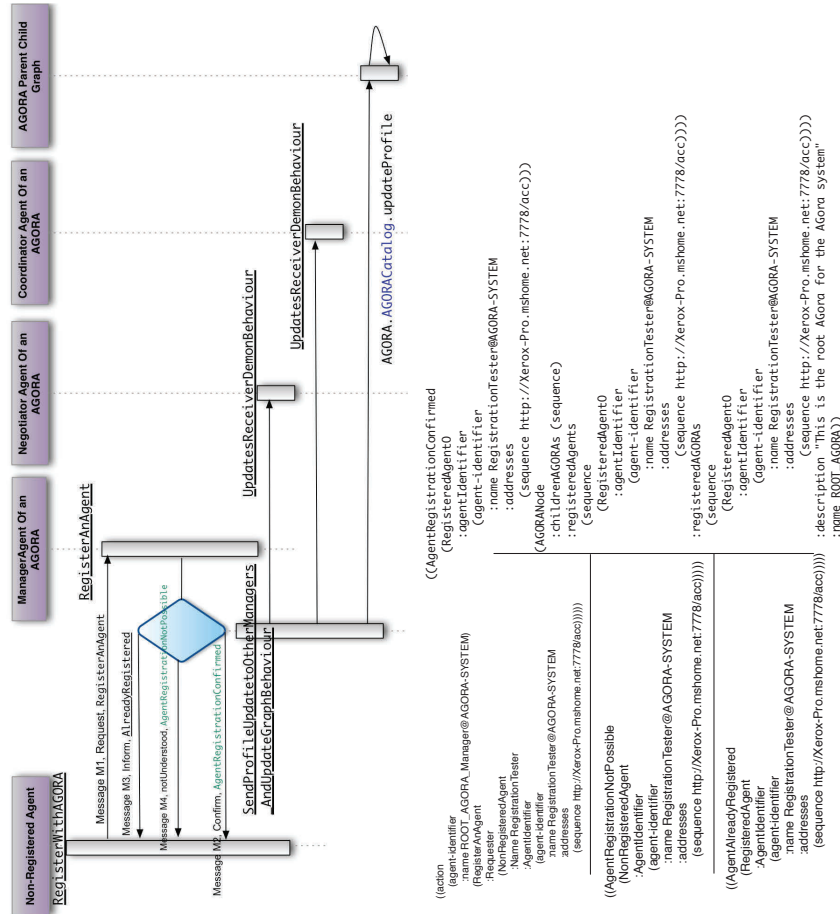
Figure 37: Agent registration protocol with SL communication messages

Figure **37** depicts the protocol where an external agent attempts to register with an AGORA (i.e. agent to AGORA registration). All the communication between agent and the AGORA occurs through SL communication messages that are constructed from the predicated and agent actions already defined in AGORA-Ontology. During the first step an external agent invokes the AGORA-Service by calling a supported agent action of AGORA-Manager along with an appropriate predicate. In return if the registration has occurred successfully the AGORA informs the requesting agent and sends an update to other AGORA-Manager-Agents about the registration. AGORA-Manager also updates the AGORA parent-child graph, so that other interested entities can learn about this registration when needed by searching the parent-child graph.

8.3.3. Implementation of FABULA Server

Implementation of FABULA-Server is actually the instantiation of FF-CML that is constructed using AGORA framework. The complete implementation work was done

during two different iterations. Since the complete system is built on client-server model, consequently FABULA-Mobile-Client (discussed in next section) was also implemented in two iterations. First, iteration was done in cooperation with a master thesis student and also by hiring the same student for a summer job (Donate, 2010)[1]. The second iteration was solely performed by the author.

8.3.3.1. First Iteration

During this iteration the main goal was to implement the key AGORAs of F-MAS and services from FF-CML Service-Model. The first version of FABULA-Ontology was also constructed during this iteration. Below is the summary of main results of the first iteration.

o **Identification of *Spaces***: during the early phases of this iteration, different locations in Trondheim city were identified. The idea was to collect the GPS coordinates of all the interesting *Spaces* in Trondheim. *Spaces* were considered relevant based on the availability of wireless network

o **Implementation of AGORAs:** Several AGORAs were implemented during this iteration. The main focus was on the AGORA related to user management, *Spaces* management, and group management. Many agent protocols to invoke different services were documented and implemented [see (Donate, 2010)]

o **Implementation of Services:** mainly the services related to group creation, user management and collaboration support services were implemented

o **Learning Activity:** during this implementation work we considered that different Learning-Tasks could be combined to create a *learning activity*. A *learning activity* could be completed by an individual learner or by a group of learners

The complete implemented system was integrated with FABULA-Mobile-Client and it was possible to invoke system's services using the client software. Experimenting with the framework of *Places* and *Space* was not the main goal of this implementation therefore, the focus was only on the physical aspects of the *Space*s in the city. Much of the work done in this iteration was hardcoded; therefore the flexibility of the system was compromised. There were many lessons that we learned by performing this implementation, we learned that the reliability of the wireless network was not very high in all areas of Trondheim city. Also our idea of creating *learning activities* was not very useful.

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[1] The results presented regarding the first iteration for implementing FABULA-Server and Mobile-client it the joint effort of Donate and the thesis author. These results are discussed in greater details in his master thesis.

8.3.3.2. Second Iteration

Based on the experience from the previous iteration many improvements were made in the system. The code resulted from the previous implementation was not extended during the second iteration because of its complexity. Instead, a completely new system was implemented from scratch. During the second iteration support for *Place/Space* framework was considered to be of fundamental importance. The simple ontology which was created during the first iteration was extended to a complete *Place/Space* based CML ontology as discussed in section 8.1. An attempt was made to implement all the important features of the FABULA-Server in a flexible manner. Apart from providing the common services, the core idea in this iteration was to provide all the necessary tools and means for a *CML designer*[1] (i.e. teacher) who acts as an administrator to: **define** 1) learner profiles (so learners can use the system), 2) cities (where learners can go to learn), 3) *Spaces*, *learning opportunities* and, 4) *Learning-Tasks*. Thanks to sophisticated GUIs available in FABULA-Server it is possible for the teacher to see the ongoing learning activity in the city, thus allowing him/her to evaluate the learning outcome based on the criteria(s) he/she considers important. Another highlight of this implementation was the instantiation of content repositories to persist the learning content of the system.
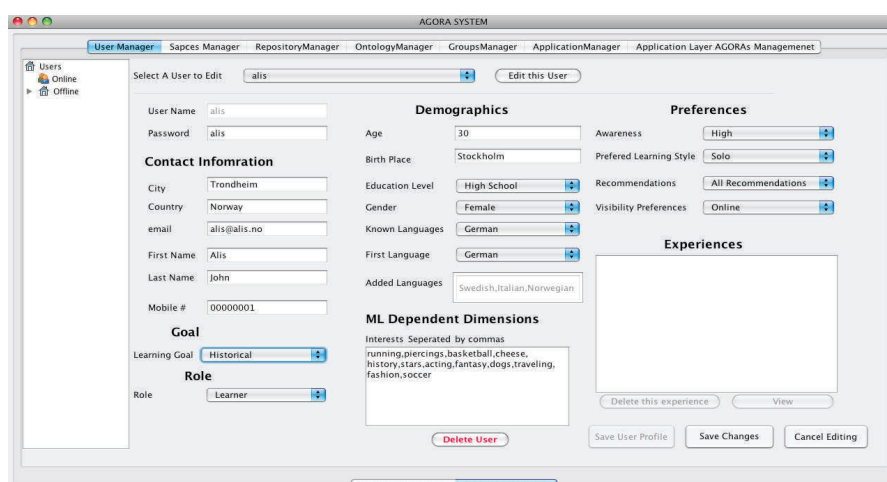
Figure 38: User Management in FABULA-Server

Similar to the first iteration the FABULA-Server was constructed over the AGORA-framework. The implementation of FABULA-Server is conveniently integrated in AGORA framework's GUI. With a single push of a button as shown in Figure **36**, the FABULA-Server can be started, upon start-up the server initializes all its variable and is

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[1] CML designer can be virtually anyone interested in adding information (Cities, *Spaces*, Learning-Opportunities and Learning-Task) into the system, however the implementation of FABULA-Server runs on PC, therefore we associate the role of adding information to the teacher. Ideally a simple web-interface will allow anyone to enter this information.

ready to provide its services to the FABULA-Mobile-client. Different types of GUIs are available to the *CML designer* (i.e. teacher). The first GUI that is available after the FABULA-Server starts-up is the user (i.e. learner) management GUI. Shown in Figure **38**, it is possible for a teacher to define learners and specify different properties of their profiles using learner management GUI. A teacher also has the possibility to edit or update the profiles and see the episodes of previous Learning-Experiences of the learners. The possibility of viewing previous Learning-Experiences of the learner allows the teacher to evaluate the learning activities of the learner. The profiles created by the teacher are kept in the FABULA-Server's user profiles repository. User-Manager-AGORA uses this information to authenticate learners.
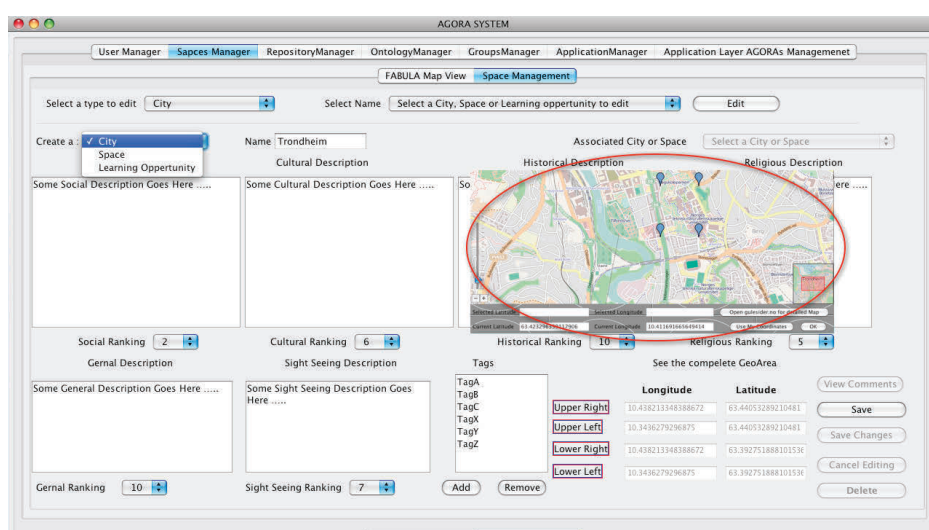
Figure 39: Physical locations management in FABULA-Server

The next important support available in the FABULA-Server is the possibility to create Cities, *Spaces*, and Learning-Opportunities. The flexible approach adopted in the system allows a teacher to create any number of cities consisting of any number of *Spaces*. *Spaces* can have any number of Learning-Opportunities, which can have any number of Learning-Tasks defined within them. With the current implementation it is possible to define any number of *Cities, Spaces, Learning opportunities* anywhere on the world's map. For the defined *Cities, Spaces and Learning-Opportunities* the system is able to provide its functional support anywhere in the world, thus the FABULA-Server is not only a solution for a particular city, instead it provides a general solution. However, due to practical reasons of inability to move to other cities, this feature has not been tested. Depicted in Figure **39** are two different GUIs, the first one allows a teacher to create, edit or delete Cities, *Spaces*, and Learning-Opportunities. The second GUI that is highlighted through a red oval allows the teacher to select coordinates of the physical locations. Furthermore, the teacher can associate *historical, social, cultural, religious, sightseeing and general* description together with ranking to the physical locations, teacher may also associate different tags with a physical location (i.e. *city,*

Space, Learning-Opportunity). The allocated ranking, description and tags are used by the system to search for the *Spaces* while creating Dynamic-*Places*.

A teacher can also associate any number of Learning-Tasks to the Learning Opportunities. This is done through another GUI shown in Figure **40**, the tasks defined in the system are kept in the learning content repository and are sent to the learner at the appropriate time. It is possible for the learner to login to the system using FABULA-Mobile-Client. The learners who login to the system appear on the FABULA-Server GUI as shown in Figure **40**. Two different learners "Alis" and "BOB" along with three different *Spaces* in the city are shown on the map of Trondheim. As the learners move through the streets of the city, their location on the map is updated on the Sever-side.

Figure 40: Learning-Tasks management and view of different online users

In this way it is possible for the teacher to have an in-depth and real-time analysis of what the learner did while visiting the city. A teacher can also redraw the movements of learners during previous episodes of Learning-Experiences. Other complementary supports available to the teacher are different types of views available to him/her.

Depicted in Figure **40** [s]he can decide to create different views by combining different kinds of information available in the system.

8.3.4. Implementation of FABULA-Mobile-Client

As we have mentioned in the last section that the implementation of FABULA-Mobile-Client was done during two iterations. Mobile-Client was implemented for Android OS based mobile phones. JADE was ported into the Android OS using a special plug-in, constructed using JADE the mobile learner was represented by a software agent that resides on the mobile devices of the leaner and communicate with the FABULA-Server and other agents on behalf of the leaner it represent.

First Iteration: During the first iteration four different kinds of activities were of high priority. **1)** The first important activity was to define the GUI for the FABULA-Mobile-Client. **2)** The second important activity was to implement the group management related functionality in the FABULA-Mobile-Client and integrate it with FABULA-Server. **3)** The next important activity during the first iteration was to implement collaboration support in the FABULA-Mobile-Client and integrate it with the FABULA-Server. **4)** Fourth and last activity that was considered was to implement the user management related functionality in the FABULA-Mobile-Client.
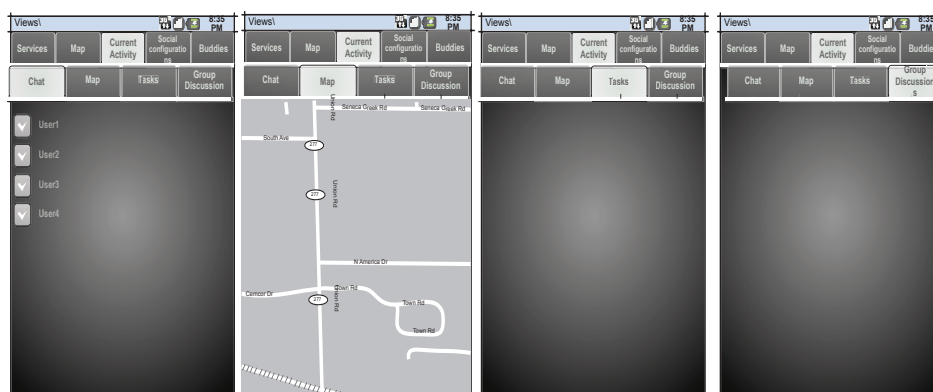
Figure 41: Different GUI's of Mobile-Client showing activity based CML

In order to design GUI for the FABULA-Mobile-Client several brain storming sessions were held. Central to the design of Mobile-Client's GUI was the idea of activity based CML (not to be mixed with activity theory). From this standpoint we considered that learner(s) learn about the city by performing learning activities. A *learning activity* was considered as a collection of different Learning-Tasks that were available in a particular learning *Space* where learner(s) was/were present. It was assumed that by performing Learning-Tasks the learner(s) learn about the city. For transforming this approach into FABULA-Mobile-Client, the GUIs were divided into two broad categories, the first category of GUI was related to the activity based learning, while the second category of

GUIs was particular to other issues that are discussed later. Figure **41** shows a model of different GUIs for activity-based learning. As an example, when a learner or group of learners are performing a learning activity, the *current activity* become available and learner(s) could see services that are specific (i.e. contextual) to the *current learning activity*. A learner can see him/her[self] on the map along with other learners. [S]He could also see the information about his/her current Learning-Group (called social configuration during this iteration) if any, under the *Social configuration* tab. [S]He can also invoke collaboration services that are also specific to learning the activity at hand.

The second Category of FABULA-Mobile-Client's GUI addressed the general issues such as common services, general map view showing all the *Spaces* and learner in the city, general groups (i.e. social configuration) related information and his/her friends. Figure **42** depicts the GUI's related to general management of CML. The idea was that by using these GUI's it would be possible for the mobile learner to see a general map, invoke general services, contact his online friends and manage his/her groups.
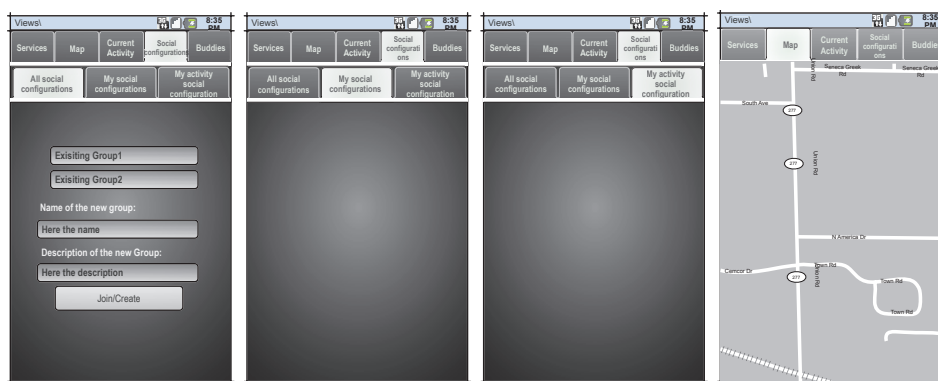
Figure 42: Mobile-Client's GUI models showing general aspects of CML

Group management features were also considered important during the first iteration. It was considered that there could be a number of groups in the system. A leaner can create his/her own groups or can join other existing groups in the system. The idea was similar to long lasting discussion groups (e.g. *Facebook group*). We also considered that there could be different types for groups such as those discussed in (Canova Calori, 2009). However, due to the lack of time and little relevance of creating complicated groups support, the groups were implemented as a simple collection of learners. Using the GUI of FABULA-Mobile-Client a leaner could create or join the groups.

Collaboration support service as discussed in FF-CML were also partially implemented, specifically we considered the implementation mobile chat service where the learner can communicate with another learner or groups of learners. User Management services were also implemented and integrated with the FABULA-Sever. These services made it possible for the mobile learner to login to the FABULA-Server and use its services. Figure **43** shows implemented view of Mobile-Client's GUIs from where the learner can invoke services hosted by FABULA-Server.
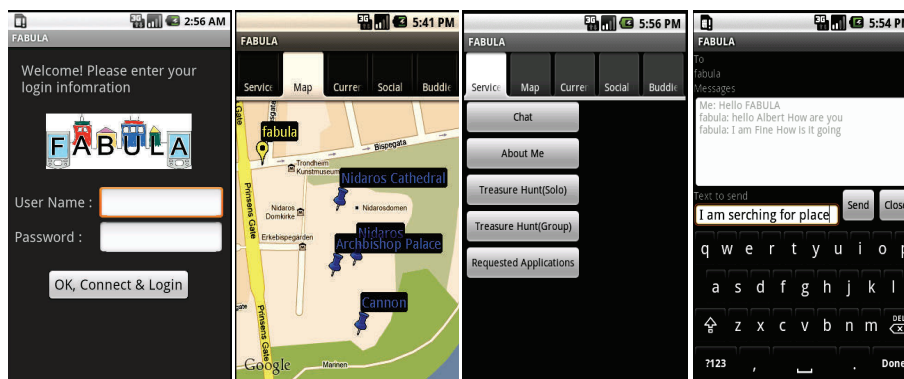
Figure 43: Implemented GUIs of Mobile-Client for invoking different service

Lessons Learned and Second Iteration: several different useful lessons were learned from the first iteration. First and the most important lesson that we learned was that in attempting to provide a comprehensive user interface we overpopulated and complicated the GUI of the FABULA-Mobile-Client. This is to say that the idea of two level tabs (e.g. see Figure **42**) in the User-Interface (UI) poorly used the precious space on the small screen of the mobile device. We also learned that complicated tasks such as asking a mobile learner to write an essay about the *Space* [s]he is visiting is not appropriate. This is natural because of the limited size of the mobile device and also due to the fact that a mobile learner cannot concentrate on the mobile device for a long time. Therefore, tasks such as multiple-choice questions, leaving a tag or comment on the visited *Space* are more appropriate. The complicated groups support was not necessary for mobile learners in the city, consideration of group as a collection of mobile learners would suffice to serve the purpose. Another important aspect that caused significant changes in the design of FABULA-Mobile-Client during second iteration was the shift of focus from activity based learning to *Place/Space* based learning. In this way the consideration of Learning-Experiences became fundamental for FABULA-Mobile-Client during the second iteration.

Considering learned lessons as input during the second iteration the GUI design of FABULA-Mobile-Client was completely redesigned and was simplified by eliminating the nonessential information from the UI. Since many of the general services were already experimented with during the first iteration, therefore the second iteration focused on implementation and integration of services related to *Place/Space*. The issues related to *Place/Space* were kept transparent from the learner, from learner's point of view [s]he visits a *Place* and the Learning-Experiences are created which are kept in the system for its use or are available to the teacher on the FABULA-Server to review them. But the information about Learning-Experiences was not available on the learner's device. Noticeable to the learner is the behaviour of the system that starts the learning from the point where the learner left it last time or the system's assisting approach to send the Learning-Tasks to the learner which [s]he was not able to perform correctly. Using the FABULA-Mobile-Client, the learner can decide his/her Learning-Goal and make changes in his/her profile so that the system may adapt accordingly.

8.4. Summary

This chapter has summarized our complete approach to design a CML support system by providing a complete overview of all the implementation work. Mainly we have discussed the implementation issues of AGORA and the implementation of *Place/Space* framework that is built using the AGORA framework. Careful articulated FF-CML and F-MAS provide clear specification of services and AGORAs for smooth functioning of the system. The CML ontology presented in this chapter is at the core of all the implementation. This ontology encapsulates all the major aspects of CML and is the result of several refinements. FABULA-Server and FABULA-Mobile-Client are implemented and are integrated together, both of them use FABULA-Ontology for supporting CML. The transformation of theoretical description into implemented software artefacts allow a teacher to convert physical locations in a city into a collection of learning *Spaces* for CML, it also allows the teacher to manage learners. The collection of tools implemented in FABULA-Server help the teacher to analyze and evaluate CML against the parameters [s]he considers important. The Mobile-Client implemented during this work allows the learners to login to the FABUA-Server and take advantage of *Spaces* and Learning-Tasks defined by the teacher. Thus, with all the different components (i.e. Server, Client, and Ontology) of the system working together, a technological solution is built using different theories to support CML.

Part IV – Evaluation and Future Directions

Chapter 9

Evaluation

Evaluating informal learning becomes, then, problematic in the sense that traditional methods of evaluating learning outcomes by assessing change after a carefully structured learning intervention are not applicable – at least not without dramatically changing the nature of informal learning (G. N. Vavoula et al., 2005).

Research Results part of this thesis has presented all the main research results of this work. While presenting the research results on a few occasions we have briefly argued about the validity and usefulness of the research results, thus attempting evaluation. However, there is a need for a clear and strong argumentation about the usefulness of this work, in other words there is a need to evaluate this work. To fulfil this need this chapter will take an analytic and critical look at all the aspects of our work and will attempt to evaluate the quality of contributions made by the virtue of this thesis. A recapitulation of the work presented in this thesis can be generalized into two main contributions that will be evaluated. The first part is the **technical solution** that is grounded in different theories and consists of FF-CML, specialization of AGORA, Mapping of *Place/Space* into AGORA, Representation of Learning-Experience, and FABULA-Ontology. The second part, which perhaps is more implicit and difficult to evaluate is the **quality of CML support provided by the technical solution**. Regarding the second part, we have stressed from the very beginning of this thesis that the main goal of this work is to *provide tools and means to support CML,* more specifically the vision was to create a solution that can *support informal mobile learning about the city by being in the city*. Providing evaluation of the research results as the central theme, **Main aim**—*of this chapter is firstly to* **evaluate the technical solution** *that consists of several sub-components and secondly* **to evaluate the quality of support available in the technical solution for CML**.

9.1. Answering the Important Questions

Even before we make any effort to evaluate the results presented in this thesis. It is important to answer some general questions regarding this research. By answering these questions it will be possible to properly evaluate the research results. Answering these questions will also define the boundaries and will limit the scope of the evaluation activity. Cohen and colleague (Cohen & Howe, 1988) have suggested a few of the most important questions that shall be answered. We will now go through the relevant

questions[1] presented by (Cohen & Howe, 1988) and will try to answer them. The answers to these questions will provide the foundation and guiding input over which the rest of the evaluation activity and all its sub-steps stand.

9.1.1. Improvements Introduced by the Approach?

To summarize in a few words: our approach to support CML uses proven and established *Place/Space* framework together with a framework of experience and map them into a technical framework called AGORA that is specialized to support CML. Furthermore, in an attempt to create the design and implement functionality of the system, we also created FF-CML (to define the needed services). FF-CML consists of Services-Model and F-MAS (AGORA based Multi-Agent System to provides services and perform other operations). Finally, FABULA-Ontology is created as a knowledge model to encapsulate all the relevant concepts and relationships into ontology that can be used by the system.

Some of the approaches that are similar to our approach have been presented in the literature, section 5.5 has discussed these approaches, where researchers have attempted to model the learning *Space* to assist the learner to learn. In comparison to previous approaches there are several improvements that are introduced in our method. To be more particular and explicit, our approach considers *Place* and *Learning-Experience* that has not been considered for supporting *informal ML about the city by being in the city*. The usefulness of *Place/Space* is proven in very similar domains and thus cannot be questioned; furthermore consideration of Learning-Experience permits a teacher to seize the unfolding aspects of CML. The technical solution created to support CML is created using software agents that are capable to perform in a dynamic environment such as city. Although software agents have been fully or partially used in other projects to support learning, the main improvement is the application of the AGORA framework that naturally matches to the notion of *Place/Space* and considers learning from a collaborative point of view and provides supporting mechanism and components. FABULA-Ontology ensures that the most relevant concepts of CML are considered during the operation of AGORA-based F-MAS.

9.1.2. Does a Metric Exist to Evaluate the Approach?

Regarding the second question it is important to underline that there is no clear cut metric to evaluate and quantify if the CML (i.e. learning) occurred through our proposed (or any other) approach or not. In general, much of the ML literature and well known authors such as Traxler, Vavoula, Sharples (J. Traxler, 2007; John Traxler, 2009; G. N. Vavoula et al., 2005; Giasemi N Vavoula & Sharples, 2008) and others are in agreement that systematic evaluation of informal ML is extremely difficult and in some cases not possible.

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[1] The question are not verbatim version of the ones presented in the source paper, but are adopted to the context of this work. Furthermore, not all the questions are considered

As discussed during section 2.8.4, that the outcome of ML and CML is **Know-How** about some subject of learner's interest. The difficulty in the evaluation lies in the fact that "***Know-How***" achieved through CML has no clear results and is a cognitive process that occurs inside the learner's head. Evaluating the quality and quantity of such Know-How is extremely difficult, partly based on this difficulty many authors [as discussed during section 7.1] tend to call the informal ML as an experience of learning. Having said that we also do not want to completely wipe out the possibility to perform any sort of evaluation, however such evaluation can be performed by a teacher. As we shall discuss and show later that the system created as a result of our approach provide supporting mechanisms for a teacher to perform such evaluation based on his/her defined evaluation criteria.

In the light of the argument provided in the previous paragraph any *approach* and its resultant technical solution intending to provide support for experiences of informal ML, particularly CML should consider some fundamental characteristics. In this thesis these characteristics are obtained from the analysis of the literature and were discussed during section 2.8.4. Based on these characteristics a quality metric can be derived to evaluate the technical solution and the quality of support provided by a technical solution. Constructed from the analysis of literature, following are the main characterises which can be used as a **metric to evaluate** our approach, the resultant technical solution and the quality of its support for CML. The Objective nature of CML shall be supported. The ***Objective*** of CML defines what one is trying to achieve though CML, this shall be taken into account. CML is characterized to be ***goal*** and ***intention*** driven, learners shall have the possibility to select different Learning-Goals and pursue them. It shall also be taken into consideration that the approach will be applied to support ***informal and contextual learning***. The learner shall have ***control*** over the ***continuous*** process of learning. It shall be possible for the learner to ***learn alone or in groups***. The mechanisms for delivering learning content to the learner shall be ***light weight*** in terms of concentration required on part of mobile learner and the amount of bytes which flow over the network. Another part of the technical solution is FF-CML, the quality of which can be unveiled by comparing it against the existing frameworks and the requirements it is supposed to fulfil.

9.1.3. Does Approach Rely on Other Approaches?

The approach presented in this thesis does depend on other previously worked approaches such as ***Place/Space*** framework (Casey, 1993; 1997; 1998) and McCarthy & Wright's (McCarthy & Wright, 2004; Wright et al., 2003) ***framework of technology as experience***. Furthermore, our approach also ***extends AGORA*** framework to specialize it for CML.

9.1.4. What are the Underlying Assumptions?

A major underlying assumption in the context of this thesis is rooted in previous works [discussed during chapter 2], which proclaim that some ***learning does occurs when the***

learners engages in informal learning activities through their mobile devices. Based on this assumption it is believed that by providing automated support for CML it is possible for the learners to absorb new skills and information, thereby resulting in the improvement of learner's knowledge about a subject.

9.1.5. What is the Scope of the Approach?

We have tried to provide generic and re-usable research results, so that these results can be use by other researchers having similar research interests. However, since the main focus of our work was ***informal citywide mobile learning***, therefore the scope of our approach is particular to the area where it is intended to be applied. This being said, there are certainly possibilities to adapt our approach and its results elsewhere, however discussing them is beyond the scope of this chapter.

9.1.6. What is the Relationship Between Problem and Approach?

We have provided clear and strong argumentation about the relationship between our approach that consists of several sub-components (i.e. *Place/Space* framework, Experience, AGORA and FABULA-Ontology) and the nature of support needed for CML during section 7.1. Firstly *Place/Space* framework is a natural match for CML, this is because a city also consists of different locations and adopting notion of *Space* allows taking into account different aspects of physical locations. Secondly notion of *Place* brings into light the issues related to the understanding of *Space.* Thus, allowing to not only to concentrate on physical aspects, but also the meanings associated to physical *Spaces*. Thirdly, on one hand the conceptualization of Learning-Experience is strongly linked to *Place/Space* framework and on the other hand ML literature tends to discuss ML as an experience of learning. Because, our work is focused on CML, therefore the experiences that occur by visiting the *Spaces* of a city with a goal to learn about them are exactly the CML experiences which need to be supported by this work. Thus, both the *Place/Space* framework and the ML's literature complement our choice of using the conceptualization of Learning-Experience. Fourthly, AGORA as a Multi-Agent framework matches the *Place/Space* framework as it based on the metaphor of marketplace. AGORA provides firsthand support when CML activities are considered as cooperative activities needing support for communication, coordination and negotiation. Finally, FABULA-Ontology provides a knowledge model consisting of concepts that are most relevant for CML.

9.2. Evaluating the Technical Aspects

The implementation presented in previous chapter justifies the validity of our approach. However, different aspects of our approach need to be evaluated, to suggest how good or how bad the approach is. Five different technical aspects related to this work can be evaluated.

9.2.1. Evaluating FF-CML

FABULA Framework for Citywide Mobile Learning (FF-CML) is yet another framework that is intended to define the aspects of CML. FF-CML itself is generic and re-usable thus it can be applied in a number of other situations. As discussed earlier, by definition a framework provides an abstract definition of the functionality and the components providing this functionality. FF-CML consists of two main parts, firstly Service-Model that defines the different types of services required for CML. Secondly, a Multi-Agent System based on the AGORA framework also called F-MAS.

FF-CML is not an outcome of some random engineering approach; instead it is based on the literature studies and takes input from the previously existing frameworks. Constructing on the input from previous frameworks, FF-CML introduces several changes and additions. It is not our intention to suggest that previously existing frameworks are poorly designed. Instead, those frameworks have some limits when considered in the context of CML. FF-CML attempts to overcome those limitations. Evaluation of FF-CML can be made in two different ways.

Firstly, a comparison between previous frameworks and FF-CML can unveil how good or how poor FF-CML is. An evaluation metric to evaluate frameworks for supporting learning was introduced in section 3.6. We will use the same metric to evaluate FF-CML. Briefly mentioned below are the main parameters [detailed discussion can be found in section 3.6] against which FF-CML will be evaluated.

- o **Abstract:** A framework that is too abstract and cannot be instantiated is not very useful
- o **Follows standards:** A framework that follows standards is better than the one that does not follow standards
- o **Service-oriented:** A services based framework is better than one that is locked into a single functional unit
- o **Involves agents:** involving software agents in the framework allows a software system to participate actively in the learning processes
- o **Considers informal learning:** in this work we are more interested in the framework that can support informal learning
- o **Contextual aspects of learning:** a framework shall take into consideration the nature of learning activity and the factors affecting it
- o **Situatedness support:** A learning framework that considers the aspects of situated learning and provides for its support has advantages over one that does not
- o **Concrete services description:** A framework should also suggest the finer details of the learning services
- o **Collaboration support:** Collaboration support includes things such as taking a combined decision, group discussions, creating an artefact together (document, drawing etc.).
- o **Interoperable:** a framework should consider interoperability with other systems
- o **Extensible:** It should be possible to extend the system with new learning services

Table 4: Evaluation of FF-CML

Evaluation Parameter	Result	Explanation
Is FF-CML instantiatable?	Yes	The implemented system presented in this thesis is an instantiation of FF-CML
Does FF-CML follows standards?	Partially	Although FF-CML's implementation when done using AGORAs from FF-CML mainly uses FIPA standards and can also use W3C standards, however FF-CML itself is not binded to any particular standardization body
Is FF-CML service-oriented?	Yes	FF-CML is service-oriented framework
Does FF-CML involve agents?	Yes	FF-CML considers agents as very important building blocks of the whole framework. F-MAS is a Multi-Agent System proposed by FF-CML for supporting CML
Does FF-CML consider informal learning?	Yes	FF-CML is designed for citywide informal learning
Does FF-CML take into account the contextual aspects of CML?	Yes	By considering the *Place/Space* and Learning-Experience, FF-CML takes into account the contextual aspects of CML
Does FF-CML provide situated support?	Yes	Since FF-CML considered learning that is situated in the city, it does considers the situated aspects of CML
Does FF-CML provide concrete services description?	Partially	The implementation of FF-CML presented in this thesis does provides concrete description of the services, however FF-CML itself done not provides the implementation level details of the services. We have adopted this approach to stay generic and to provide a reusable framework
Does FF-CML provide collaboration support?	Yes	FF-CML has a dedicated service category to provide the services for collaboration support. Some of these services are implemented during the implementation of FF-CML
Is FF-CML Interoperable?	Yes	The implementation of FF-CML is interoperable with other frameworks as it follows standards. Furthermore, by using AGORA-Ontology any external agent can interoperate with AGORAs of FF-CML
Is FF-CML Extensible?	Yes	FF-CML is extensible because more functionality can be created over the basic services described by FF-CML

Table **4** presents the evaluation of FF-CML, in comparison to the evaluation of previous frameworks presented in Table **3**, FF-CML scores better. Based on these results adoption of FF-CML for CML system will yield better results. This is because FF-CML is tailored to support informal CML and is focused on delivering support in dynamic environments such as a city. Its consideration of several aspects that are relevant to CML makes it a better candidate that is more robust and useful.

Secondly, FF-CML can be evaluated against the requirements that were presented in section 6.3.1. Similar to the evaluation parameters discussed in previous paragraphs, the following were the important requirements for the design of FF-CML. *Service-based, support for learning groups, possibility for the learners to communicate and collaborate with each other, support for structuring the learning Spaces in the city, proactive behaviours such as recommendations, manage information about learner and learning content.* All the requirements are considered during the design and are fulfilled. As discussed earlier FF-CML is service-based, it considers learning groups and contains special AGORAs (i.e. Group Manager and Group AGORA) and services to provide group related support. FF-CML also specifies the name and types of communication and collaboration support services. It also manages the learning *Spaces* which exist in the city and has special AGORAs (i.e. *Spaces*-Manage and Space-AGORA) to provide the *Spaces* management related support. Overall proactive support is provided by the inclusion of software agents and has been demonstrated for recommendation. Management of user profiles and supporting services are also part of FF-CML.

9.2.2. Evaluating Mapping of *Space*, *Place* and Experience

The mappings of learning *Spaces*, *Places and experiences* were presented in chapter 7. Because of the fact that theoretical concepts are mapped into technology it is not straightforward to calculate some percentage to suggest if our proposed mapping is good or bad. However, there are three aspects based on which mapping approach can be evaluated.

- o   Firstly, we can evaluate how well the theoretical concepts are actually mapped?
- o   Secondly, evaluation can be made in comparison to previous works
- o   Thirdly, it can be questioned as to how much this mapping permits other parts of the systems to support the characteristics of CML, which were discussed in section 9.1.2

In connection to the first aspect, the mapping of *Space* is done in as realistic way as possible. Theoretically, *Spaces* have physical attributes and are of certain types, such as *historical, social, cultural, religious and sight-seeing*. All these aspects are taken into consideration during the mapping process of *Space*. Aspects related to defining physical boundaries, ranking and types of *Spaces* were mainly considered. The theoretical conceptualization of *Place* is discussed in theory as a meaningful location. The process of meaning making occurs through Learning-Experience. Learning-Experience acts as a bridge that connects *Spaces* to the learners. However, representing the notion of

meaning is difficult due to the lack of expressive power inherent in computer programmes. Moreover, it is not clear what exactly theory means when it describes *Place* as a meaningful location. It becomes even more difficult when the experiences of *Place* are different for each individual. Narrative description of *Place* as a theoretical concept does not impose any limits on the size of *Place,* therefore a *Place* can be a university for an individual, however for another individual a *Place* can be a city or a country or a continent and so on. Mapping these rich narrative descriptions with all the details discussed in theory is not possible. For example how can we represent experience, which occurs differently for each individual? As a first step to translate theoretical descriptions, we have extracted important attributes from two different frameworks discussing experience. These attributes were further divided into two types, namely translatable and non-translatable attributes. The mapping approach only considers the translatable attributes to represent Learning-Experience and mainly focuses on the type of activity and number of Learning-Tasks performed by the learner under certain conditions (i.e. other learners, time, etc.). Furthermore, mapping of Learning-Experience also takes into account the feedback provided by the learner to the system. Based on Learning-Experience, *Place* is created over *Space(s),* the behaviour of *Place* is directly derived from the previous Learning-Experience of an individual. The main consideration for creating *Place* is the number of Learning-Tasks that are already and correctly performed by the learner. The created *Place* then sends the Learning-Tasks to the learner that are either not performed or incorrectly performed. The mapping process also considers two different kinds of *Places* (i.e. static and dynamic) thereby allowing us to overcome a limitation of theory that defines no limits about the size of *Place*. As future consideration the mapping of *Place* and Learning-Experience need more clarification and elaboration as to what does it means to associate meanings with a *Space*.

In comparison to previous work our proposed approach not only considers the physical aspects of location, but also to associate some meanings with it. Such an approach is more useful and expressive than the previous works, which mainly augment *Space* to know the position of the learner [discussed during 5.5]. There is a huge literature [briefly discussed in section 5.1] that highlights the importance of the role played by the location (*Space, Place*) where (learning) activity occurs. In other words it is established reality that learning activities do not take place in an isolated vacuum, but are affected by and affect their environment. Adoption of *Place/Space* and experience frameworks allows capturing important aspects of learning locations that were not considered by the previous approaches.

The approach for mapping *Place/Space* and experience adopted in our work complements system's consideration of a ***few*** important characteristics [discussed in 9.1.2] of CML. Since the focus of this work is on CML, the concept of learning *Space* that is ranked and augmented by *Learning-Tasks* allows the system to support learning that is driven by the ***goal*** and ***intention*** of the learner and has some ***objective***. In other words, this work mainly focuses on learning about the city. The consideration that a city consists of a collection of *Spaces* allows the learners to learn about a particular aspect of the city. Learning-Experience provides information about the Learning-Tasks that have been performed by the learner(s) at some location. The *Place* that is created based on

the previous Learning-Experiences is thus ***contextualized*** and allows support for the ***continuity*** of the previous Learning-Experiences.

9.2.3. Evaluating Extensions in AGORA Framework

The extensions introduced in the AGORA framework are intended to streamline AGORA for CML. General conceptualization of an AGORA is a market place where cooperative activities take place. Following are the main extensions that are introduced in the AGORA framework, 1) AGORA-Node, 2) AGORA-Parent-Child-Graph, 3) AGORA-Registration-Graph, 4) AGORA-Ontology, and 5) A-MASSEM. Because of the fact that *Place/Space* framework is mapped to AGORA framework, the introduced extensions in AGORA framework can be evaluated by examining how well the proposed extensions match and complement the *Place/Space* framework.

The concept of AGORA-Node that is being introduced in AGORA framework directly matches to concepts of *Spaces* and *Places* which exist in the city. Several *Spaces* and *Places* can exist in the city, each having different kinds of information attached to it. For example a *Space* can have information about its geographical coordinates, tags, comments, different types of ranking, different kinds of descriptions, Learning-Opportunities, and Learning-Experiences that have occurred in the *Places* that have been created over the *Space*. Thus, each *Space* is like a small database of information. Collectively, all the *Spaces* in the city are like small databases distributed in the city. Since each *Space* is managed by an AGORA, the AGORA-Node of the AGORA managing a *Space* keeps all this information about the *Space*. The concept of AGORA-Node directly matches and support the concepts of distributed *Spaces* in the city. All three AGORA-Manager-Agents have the possibility to share this information and function according to this information.

AGORA's Parent-Child and Registration graphs also support the concept of *Space* and *Place*. As discussed during section 7.3, five different types of *Space's* networks are created in the system, where each network is related to a particular aspect (i.e. history, culture, sight-seeing, religion, and social) of the city. The concept of different network of *Spaces* matches the AGORA-Registration-Graph. Furthermore, in order to create Dynamic-*Places*, relevant *Spaces* need to be searched. The availability of two different kind of network in AGORA framework allows performing the search.

The AGORA-Ontology provides a data-model for the whole AGORA framework, the availability of such ontology does not directly influence or support CML. However, with the presence of AGORA-Ontology it is possible for agents in the AGORA framework to use SL-language as the content of their communication messages. By using SL language it is possible for the agents to communicate, coordinate and negotiate in a semantic rich and flexible manner. In other words, in the presence of AGORA-Ontology agents do not need to communicate using hardcoded String based messages, instead the content of their message can change without recoding the complete communication protocol. In terms of support of CML, availability of such flexibility is

in some cases necessary when the contents of agent communication messages cannot be predicated at the implementation time.

A-MASSEM is an agent engineering methodology to create AGORA based Multi-Agent Systems. The main usefulness of A-MASSEM was highlighted when the FF-CML was created using it, thus it has indirectly contributed to providing the supporting mechanisms for CML. An evaluation of FF-CML has already been provided previously. However, there is no direct link between CML and A-MASSEM, for this reason providing an evaluation of an agent oriented software engineering methodology is beyond the scope of this chapter.

9.2.4. Evaluating FABULA-Ontology

FABULA-Ontology is at the core of FABULA system as; it provides a common knowledge model for all the subcomponents of the system. In order to be useful for CML, FABULA-Ontology should include all the important concepts that are relevant for CML. In other words all the important characteristics of CML will be significantly represented in FABULA-Ontology. For evaluating wether the FABULA-Ontology significantly represents all the important characteristic of CML [discussed during section 2.8.4 and 9.1.2] can be used as a metric of evaluation.

Table 5: Evaluation of FABULA-Ontology

Characteristic of CML	Result	Explanation
Does FABULA-Ontology represents the *objective* nature of CML ?	Yes	The presence of concepts such as *Space*, *Place* and Learning-Opportunities in FABULA-Ontology is proof of the fact that FABULA-Ontology supports and represents the objective nature of CML. In context of this thesis the objective of CML is to learn about the city, therefore the concepts of *Space* and Learning-Opportunities represent the location in the city about which a learner can learn.
Does FABULA-Ontology contains the concepts representing *goal and intention* orientedness of CML?	Yes	FABULA-Ontology contains a special concept representing the Learning-Goal of the learner. A learner can choose a goal among six different learning goals. It is true that the numbers of goals a learner can choose from are limited and are hardcoded in the system. However, allowing a learner to define his own Learning-Goal is difficult, this is because understanding learner's Learning-Goal that can virtually be anything and adapting system's behaviours accordingly can start a new thread of research work with no

		direct relevance to CML.
Is FABULA-Ontology targeted to support *informal* CML?	Yes	There are no concepts in FABULA-Ontology that can be used for a formal type of learning; such as courses, assignments and examination. Instead it is focused on an informal type of learning and provides a knowledge model to capture the interests and preferences of the learners.
Does FABULA-Ontology allows *contextual and continues* nature of CML?	Yes	There are concepts in FABULA-Ontology such as the position of the learner, preferences and Learning-Experience. Through the use of these concepts it is possible for the system to behave in a context aware manner. When the learner decides to take a pause in the learning, the information about the activity is saved as an episode of Learning-Experience, when the learner wishes to start the learning the process starts from where [s]he paused, thus supporting the continuous nature of CML
Does FABULA-Ontology allow learners to *control* CML?	Yes	There are concepts in the FABULA-Ontology which allow learner to decide his/her Learning-Goal. Learner can tell the system if [s]he wants to act as a teacher or a learner. Learner can also decide his/her preferences such as if [s]he wants to be learner in group or solo, how much recommendation he/she wants etc. Pausing and starting the learning at anytime is also under control of the learner. Ontological concepts supporting such operations allow the learner to take full control of the learning
Does FABULA-Ontology represents the concepts for supporting *grouped and solo* CML?	Yes	There are concepts in the ontology supporting this characteristic.
Does FABULA-Ontology consider *lightweight* learning?	Yes	The Learning-Task that is an ontological concept actually represents multiple-choice questions. These tasks are lightweight in terms of concentration required by the learner and the network bandwidth needed to deliver the tasks to the mobile device.

An evaluation of FABULA-Ontology is presented in Table **5**, as can be noticed FABULA-Ontology considers all the important characterises of CML and represents

them comprehensively. The presence of concepts that are important in CML is the evidence that FABULA-Ontology is useful for CML. Since, this ontology provides support for all the important characteristics of CML, therefore it also complies to the literature of ML in general and CML in particular.

9.3. Evaluating the Quality of Support for CML

As we have discussed previously it is not possible to measure if any or some learning has occurred when a learner uses his/her mobile device to get some *"Know-How"* about the subject that interests him/her. However, based on the assumption discussed in section 9.1.4 that learning supports available in the system can be evaluated. Generally speaking there can be two different kinds of roles a learning peer can play. [S]He can either decide to act as a teacher or as a learner, from this stand point the quality of support available for the teacher and for the learner needs to be evaluated. Two use-cases are presented in the next sections, one for the learner and another for the teacher, based on these use-cases an evaluation of the support available for each of the peer will be evaluated.

9.3.1. Evaluating Support for Teacher

Use-Case: a teacher at a local school in Trondheim wants to take 7 students for a visit to the city. Through this visit she want her students to learn about important historical locations (i.e *Spaces*) in the city. The teacher is particularly interested to help her students to learn about two important historical locations. Firstly, she want them to learn about the history of "Nidaros Cathedral[1]" secondly, she wants her students to learn the history of "Archbishop's Palace". In these two locations (i.e. *Spaces*) there are a few important pieces of information that the teacher wants to highlight. However, she doesn't to give this information to the students in a verbal form, instead she wants the students to be present in the location (i.e. *Space*) where this information would make more sense and would be easy for her students to recall later. Furthermore, the teacher want to know how well her students did when they actually went to the city. She has some self-defined evaluation parameters that she wants to use to evaluate the progress of her students.

Evaluating Support for Teacher: Everything that teacher wants to do is easily available in the FBULA-Server-Application. The availability of all the functionality discussed below demonstrates the support available in the system for CML. Firstly, the teacher has to open the FBULA-Server-Application and create 7 different learner profiles for her students. This support is easily available in the FABULA *user management GUI* depicted in Figure **38**. Since, the teacher is interested in just two locations in the city. The functionality to define different locations is also available for the teacher. She can define these two locations in the system by using the *Space management GUIs* shown in Figure **39**. After defining the location the teacher can create different Learning-

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[1] http://en.wikipedia.org/wiki/Nidaros_Cathedral

Opportunities and define different multiple-choice tasks available within those Learning-Opportunities, this can be easily done by the teacher by using the *repository management GUI* presented in Figure **40**. By creating the Learning-Tasks in a particular Learning-Opportunity, her student will only get to do those tasks in the specific location she chose.

After performing the above mentioned activity, her students will now be able to login to the FABULA-System using the credentials their teacher defined for them. When the teacher actually takes her student to the locations she wanted them to visit, the multiple choice question about *Nidaros Cathedral* and *Archbishop's Palace* will appear on their mobile devices. After finishing the visit the teacher can use the FABULA-Server-Application once again to perform the evaluation. She can look into the details of the answers to multiple-choice questions to review if her students have answered the tasks correctly. She can also see the trace of individual student's movement within the city along with the specific locations where the tasks were actually answered by the students. Using this information she can perform the evaluation of her student's learning outcome based on her self-defined criteria. The evaluation could have become more through and comprehensive had the teacher decided to stay in front of FABULA-Server-Application while the students were visiting the city. In that way, it would have been possible to see the activities of her students in real time.

9.3.2. Evaluating Support for Learner

Use-Case: A learner named "Alice" has just arrived in Trondheim for a semester to study at NTNU. There is still some time before the class will start; "Alice" decides to go out for a visit of Trondheim city. She is not interested to learn about any particular aspect of the city, so she set her learning goal (goal = *learn about city*) to generally learn about the whole city. Furthermore, since she is not familiar with any other user of FABULA she decides to learn alone.

Evaluating Support for Learner: since "Alice" decided to learn about the whole city, the learning pattern that matches her goal and Learning-Style is "*Solo Learner in Static-Places (SLS)*" [discussed during section 7.6.1]. In this scenario, Alice is a learner who knows nothing about the city, when Alice goes to the city with the FABULA-Client-Software installed on her device. The FABULA-Server detects her position in the city, using this information it can also identify the *Space* that is being visited by Alice. As Alice moves within that *Space* the FABULA-Server send a number of multiple-choice tasks that she can perform. These tasks encourage Alice to explore her surrounding *Space* to correctly answer the questions. By the time Alice finished her visit, she managed to visit four different *Spaces* in the city and performed a number of tasks that were available in those *Spaces*. The information about her first visit along with four different Learning-Experiences are saved in the system and can be used at later time when Alice wishes to visit the same *Spaces* again. Based on the assumption made during section 9.1.4 it can be concluded that before Alice made a trip to the city she had no knowledge of the different *Spaces* in the city. However, after using the FABULA

system, her knowledge about the city improved. Thus, through the support available to Alice as a learner, she was able to learn new things and her knowledge has improved.

9.4. Summary

This chapter has provided a detailed evaluation of all the research results presented in this thesis. In order to perform the evaluation, this chapter has answered some of the most important questions related to this work. Answers to these questions provide a general evaluation of the overall work; these answers have also established a relationship between our proposed approach and the problem domain. After defining the scope and underlying assumptions, all different sub-components of this work are evaluated against the suitable evaluation merit. Form the technical point of view; this chapter has evaluated FF-CML, extensions in AGORA framework, FABULA-Ontology, mapping of *Space*, *Place* and Learning-Experience. From quality of support for CML, the system is evaluated with the help of two different use-cases. FF-CML is evaluated against the evaluation metric that was extracted from the literature review; comparison between FF-CML and already existing frameworks unveiled the usefulness of FF-CML. Furthermore, requirements of FABULA were also used as an evaluation metric to check if FF-CML fulfils those requirements. The mapping of *Space*, *Place* and Learning-Experience is evaluated in three different ways. Firstly, evaluation was performed to check if the mapping comprehensively depicts the theoretical conceptualization; secondly, the quality of our approach is compared with previous approaches to model learning *Spaces*; thirdly the important characteristics of CML are used as an evaluation metric. Extensions in the AGORA framework are evaluated to check if these extensions complement the *Place/Space* based CML, for this purpose characteristics of CML are used as an evaluation metric. FABULA-Ontology that is the last important part of the technical solution is also evaluated against the important characteristics of CML. The support provided by the system for CML is evaluated from two different perspectives. The support available for the teacher is evaluated with the help of a use-case to show that its possible for him/her to define learning content in the system and then evaluate the learner's performance against the teacher defined criteria. Similarly, to evaluate the support for the leaner a use-case is used to show that different features and functionality available in the system helps the learner to acquire new knowledge about the city.

Chapter 10

Conclusion and Future Directions

After presenting all the important research results and evaluating them, it is now important to cross check our research results against the research questions. At this stage it is important to ask an important question, *did we manage to arrive at the right destination and have we been able to achieve what we intended in the first place?* It is also important to identify the issues that this work was not able to consider. Furthermore, like any other research work there are shortcomings that should be underlined, based on which future direction for this work should be proposed. To accomplish these aims, in this chapter we will revisit the research questions and will re-check our research results to see if they correctly answer the research questions. **Main aims of this chapter — *is to highlight and conclude the contributions made against research questions*,** *secondly,* ***to discuss the future direction for this work***.

10.1. Concluding the Contributions

In general the main research question that this thesis has addressed is **"*How can mobile learning about a city that consists of different interesting locations be supported by the technology through applying Multi-Agent System and services provisioning*"**.
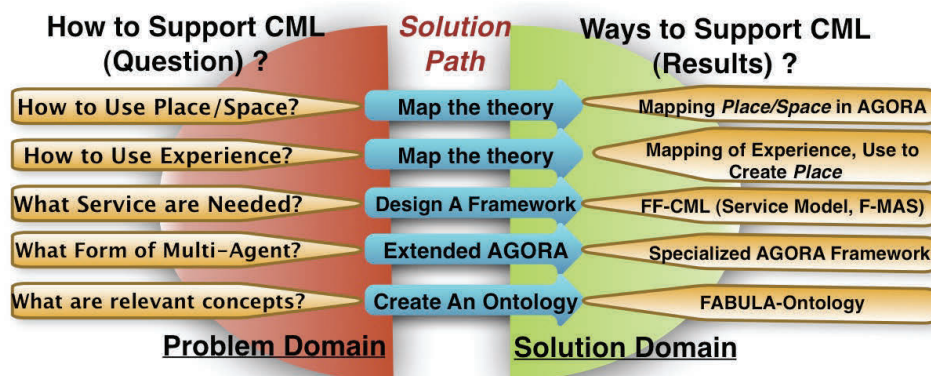

Figure 44: From research questions to research results

Figure **44** presents an overview as to how the work presented in this thesis has answered the research questions that were posed in this thesis. From the general research question stated above, five sub-questions are derived, each addressing a particular aspect of this

work. We will now iterate over all five research questions presented in section 1.2 and will summarize their answers (i.e. contributions) provided by this work.

RQ1: *Are there any theoretical foundations that can be use to model a city consisting of many sub-physical structures to support informal and situated mobile learning?*

Detailed answer available in: Chapter 7, Chapter 8 of this thesis and publications P5, P6, P7, P8 [as discussed in section 1.4] have discussed the answer for RQ1 in greater detail.

Answer for RQ1: the theoretical foundation that this work considers to be most suitable for CML is the framework of *Place/Space*. In particular, Casey's (Casey, 1993; 1997; 1998) philosophical description of *Space* as a physical structure (i.e. location) and *Place* as a logical and meaningful overlay attached to *Space* is most relevant for CML. The main argument behind establishing the relationship between CML and *Place/Space* framework in context of this work is the fact that cities are not monolithic entities. Instead cities consists of many sub-locations (i.e. *Spaces*), furthermore not all the sub-locations (i.e. *Spaces*) are interesting, in fact there are only a few interesting *Spaces* about which learners may want to learn. The framework of *Place/Space* allows to divide the city into its constituent *Spaces*. When the notion of *Place* comes into play, it allows capturing the Learning-Experiences that occur in *Place*. *Places* are created over *Space* and are particular for each individual learner. Another reason for distinctively considering *Space* and *Place* is based on the fact that this approach is proven to be successful in other similar research domains.

RQ2: *How can the "learning experience" which occurs in the city, be represented and used in a technological solution to provide supporting mechanism for citywide mobile learning?*

Detailed answer available in: Chapter 7, Chapter 8 of this thesis and publications P5, P6, P7 [as discussed in section 1.4] have discussed the answer for RQ2 in greater detail.

Answer for RQ2: There are two important aspects of Learning-Experience that needs to be represented. Firstly it is important to represent the experience of a *Place,* secondly, it is also important to consider the technological factors involved. The CML Learning Experience as represented in this thesis is constructed by intersecting with Casey's (Casey, 1993; 1997; 1998) explanation of experience of a *Place* and McCarthy framwork (McCarthy & Wright, 2004; Wright et al., 2003) of technology as expreince.

RQ3: *What are the different categories of service required to support citywide mobile learning?*

Detailed answer available in: Chapter 6 of this thesis and publications P1, P2 [as discussed in section 1.4] have discussed the answer for RQ3 in greater detail.

Answer for RQ3: Through an overview of existing frameworks and an analysis of the main requirement of FABULA, FF-CML is created. FF-CML provides a Service-Model

and AGORA based Multi-Agent System (i.e. F-MAS) for supporting CML. A number of services are identified and placed into different categories. Important parts of FF-CML are instantiated to support CML and to validate it.

RQ4: *How and what form of Multi-Agents System should be used to support mobile learning in a dynamic environment where the learning needs and location of learner is subject to frequent changes?*

Detailed answer available in: Chapter 6, and publications P1, P3, P4, P5, P6 have discussed the answer for RQ4 in greater detail.

Answer for RQ4: AGORA framework that is based on the metaphor of market place naturally matches the *Place/Space* framework. Several extensions are introduced in AGORA framework to specialize it for supporting CML. AGORA copes with dynamic and open environments by providing specialized agents for performing communication, coordination and negotiation. The AGORA framework is flexible as different AGORAs can be created and removed as needed. Constructed over AGORA framework F-MAS consists of all the important components (i.e. AGORAs) for providing support for *Place/Space* based CML.

RQ5: *What are the concepts, relationships, and patterns (i.e. configurations) that are relevant to CML that must be represented in the domain ontology?*

Detailed answer available in: Chapter 7, Chapter 8 and publication P7, P8 have discussed the answer for RQ5 in greater detail.

Answer for RQ5: By extracting the main characteristics of CML from the literature studies an ontology called FABULA-Ontology is constructed. Similarly, core patterns for CML are identified. The identified pattern of CML represent configuration of mobile learners, *Places/Spaces* and the technological components needed to support them. FABULA-Ontology takes into account all the important characteristics of CML and consists of all the important concepts and relationships relevant for CML. This ontology provides a common knowledge model that is used by the agents of F-MAS. FABULA-Ontology mainly presents the learner, *Spaces/Places*, Learning-Experience.

10.2. Future Directions

Through the research results presented above a coherent solution for CML is proposed. Although we have attempted to address all the important aspects of CML, however it was not possible to do everything in a perfect manner, therefore some aspects of this work can be further refined and can be extended in the future.

Future directions for this work can be divided into four main parts. Firstly, the conceptualization and ***mapping of Place and Learning-Experience can be extended*** in the future. The mapping of *Place* and Learning-Experience presented in this thesis is an initial attempt to map the vast theoretical explanations into technology. Since our main

focus was on technology, we considered only the attributes that can be directly translated in our mapping. However, the attributes that are declared non-translatable in this version of our work can be reconsidered and the current approach for mapping can be extended. However, for this to happen not only technical expertise is required, but experts are required who can comprehensively understand the theoretical implications.

Secondly, implementation that has been done is only experimented through emulators and is limited; in future the implementation can be extended and tested with real use-cases involving real learners. By doing so, a comprehensive evaluation can be done to analyze the learning outcome and learning support available through the use of proposed approach. Furthermore, due to the time limitations and tightly integrated AGORA GUIs, it was not possible to port AGORA framework into the mobile devices, a JADE agent was used instead. The future work can also consider to refractor the implementation of AGORA framework to make it completely independent from GUIs and port it to mobile devices.

As a third extension to this work, semantic technologies can be introduced. Learners may be allowed to provide self-defined learning goals, that can be used by the system to match against the description of *Spaces* and Learning-Task. Based on the learner's goal different kinds of *Places* can be created by the system. The current version of ontology only considers static and dynamic types of *Places;* in this respect the main consideration is the number of *Spaces* over which a *Place* is created. However, other information about learners can be used to create different kinds of *Places* dynamically.

This work only considers ML from the point of view of learning about the city. More interesting aspects can be experimented by generalizing the proposed approach for any kind of learning in the city. In this regard, a simple, multiple choice question based approach can be extended by considering other kinds of Learning-Tasks with more well defined learning content. Such Learning-Tasks should concentrate more on the collaborative aspect of learning.

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Appendix A: Selected Papers

A 1. Source of Paper P1

A Platform for Actively Supporting E-Learning in Mobile Networks

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ABSTRACT

The ubiquitous availability of wireless networks has opened new possibilities for individuals to learn from each other in open learning spaces like cities. Therefore, the changed learning environment must be understood by e-learning systems and technological facilities must be provided for knowledge sharing and construction. Such systems need to be pedagogically sound, yet adaptive to altered modalities. The teacher who was once the central entity to fulfill the learner's needs may not always be available. Therefore, e-learning systems would fill the gap created by this teacher unavailability by actively participating in learning activities and performing some of the teacher's roles. This article proposes an architecture designed to meet such challenges in a city-wide context. The authors outline the main components and services needed to fulfill the new requirements and provide the learners with tools, services and educational support for learning activities. Figure 5 reprinted with permission from IEEE Std. 1484.1 1998, Standard for Learning Technology "Learning Technology Systems Architecture (LTSA)", Copyright 1998, by IEEE. The IEEE disclaims any responsibility or liability resulting from the placement and use in the described manner.

Keywords: Active Support, E-Learning, Collaborative Learning, Informal Learning, Learning Framework, Learning Services, Multi-Agent System

INTRODUCTION

The availability of communications infrastructure alone is not enough to support mobile learning. There is also a need for well designed learning systems; these systems should take into account both technical and pedagogical aspects of such forms of learning. Such a system will provide the supporting services *(functional units)* and mechanisms *(intelligent decision*

making) to conduct learning and collaborative activities. More importantly, a learning system needs to participate actively in the learning process. As more and more information becomes available "we urgently need techniques to help us make sense of all this, to find what we need to know and filter out the rest; to extract and summarize what is important" (Davies et al., 2007, p. 1). Therefore availability of infrastructure alone cannot be considered sufficient for learning; "Media is therefore a mere vehicle that delivers instruction but does not influence

Appendix A: Selected Papers

student achievement" (Clark, 1983). In our work we do not consider a learning system to be part of the communication medium, instead we consider it to be the part of learning process itself. Thus, such a system plays an active part in learning and collaborative activities while dealing with challenges such as open environments, heterogeneity and dynamism. In this way the system should not only act as a passive medium of pre-defined communication patterns, instead it should perform an active role to increase the learning outcome. It can do this by following and assisting the learner throughout the learning process, through recommendation and filtering of relevant learning material, by understanding and evaluating the contextual learning space of the learner and adjusting the system's behavior accordingly, and thereby personalizing the learning experience for each individual learner.

While looking at the design of currently existing learning systems it becomes apparent that much of the functionality is replicated among different systems; sometimes even the data is replicated among several systems. For instance, functionality to authenticate users, retrieve and manage data in the data source or functionality to manage user information is common among learning systems. It would therefore be wiser to develop common system functions as services and not as functionality locked into a single system. A service based approach towards the system design can result in interoperability (both syntactic and semantic), an open, extensible and cooperative system (Mason, 2004; Wilson, 2005); where each service is intended to fulfill a specific learning task. Figure 1 presents the idea of how three different 'single tone' systems (Wilson, 2005) can benefit from the services based approach.

Further, to reduce the complexity of the system, categorization and layering of system components (i.e. services) assists in paying due attention to particular aspects of learning supported by the system through its functionality. Such flexibility not only complements the technical aspects of a learning system, but also has a direct influence on the pedagogical features of the system. A system that is built in a modular fashion can adapt very easily to integrating new modules (i.e. modules supporting both technical and pedagogical aspects of the

Figure 1. Transformation of single tone systems to service based systems (Adapted from Wilson, 2005)
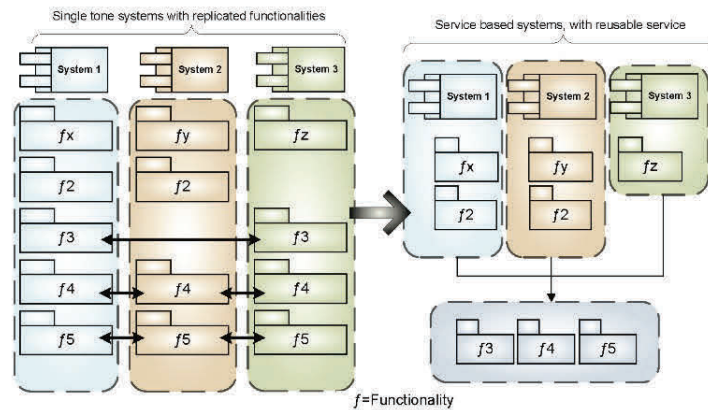
Appendix A: Selected Papers

learning). Flexibility in the core system design also allows us to evaluate different pedagogical aspects of a learning system.

INTRODUCTION TO THE FABULA SYSTEM

This article discusses project FABULA (FABULA-Con, 2007) (**F**remr**A**gende **B**y for **U**ndervisning og **LA**ering - Seamless networks for transforming the city into an arena for learning) as the main example of our designed system. Our learning system targets the technology enriched societies consisting of individuals who carry sophisticated mobile devices with them. Such individuals are also discussed as "*Cyborg*" by Løvlie (2006) and as "*Generation C*" by Bruns (2007). On the one hand our technical goal is to construct a (web-) services based e-learning system for mobile networks, while on the other hand, pedagogically, we aim to support informal collaborative mobile learning activities in a city wide context. A main consideration is to underline the fact that in such settings a teacher might not always be available to learners. Therefore, certain activities which a teacher might perform are delegated to the system and are programmed into the behaviors of the system. By considering both aspects at the same time we include the pedagogical dimensions in each phase of system design. All the theoretical aspects of city wide mobile learning are blended in the system design and reflected in the components (i.e. agents and services) of the system. Learning applications of our system allow the inhabitants of the city to fulfill a specific learning need within a specific contextual space through the use of information and communication technology. By virtue of such a system it would be possible to transform the mobile communication infrastructure of the city into an active medium for learning.

The main highlights of our work are:

*   Inclusion of pedagogical aspects from the early design stages

*   To support the informal mobile learning which takes place through interaction, exploration and serendipity (Calori, 2009)
*   To support mobile learning in a city wide contextual space
*   To introduce an active role of the system in the learning process

Generally speaking the FABULA system can be divided into two main parts. The first part consists of the *services architecture*, which deals with the services or the functionality supported by the system. The second part of the system consists of the *multi-agent system*. This part is responsible for the more active role of the system during the learning process. This latter part has a direct influence on the pedagogical aspects. Our multi-agent system performs certain intelligent tasks to increase the learning outcome of a FABULA learning activity. Both parts of our system are discussed in greater detail later in the article.

The rest of this article is organized as follows. The next section gives an overview of existing e-learning platforms. All the discussed platforms are evaluated for their strengths and weaknesses related the purpose of our work. The section after that presents the FABULA *services architecture*. The next section discusses the FABULA *multi-agent system*. The presented multi-agent system is grounded in an existing multi-agent framework called AGORA (Matskin et al., 2001). The complete architecture is elaborated using a use-case. Then a short discussion comparing our system with the existing work is presented, followed by conclusions and future work.

BACKGROUND STUDIES OF EXISTING E-LEARNING PLATFORMS

There are several e-learning Frameworks / Platforms / Architectures, which provide guidelines for designing the architecture of an e-learning system. The design of an e-learning system can benefit from knowledge of existing frameworks;

Appendix A: Selected Papers

these frameworks can help in identifying the components and services in an e-learning system. Wilson et al. (2004) suggested that frameworks can be use to identify the common services of a system.

IMS Abstract Framework (IAF)

One such framework is the IMS Abstract Framework (IAF). The core aspects of IAF (IMS-Con, 2008; Smythe, 2003) are Interoperability, Service-orientedness, Component-based design, Layering and Binding neutrality (XML, WSDL, Java, etc). IAF acts as a device which enables IMS (IP Multimedia Subsystem) to describe the context within which it develops interoperability specifications of its e-learning technology. IMS-IAF provides different views / architectures / models of an e-learning system from different perspectives. The idea is to identify different components of an e-learning system by examining it from different angles (Smythe, 2003).

IAF-Logical perspective on Architecture is a collection of six layers; each layer uses the functionalities provided by the layer underneath it. This logical ordering identifies and provides information about all the main entities/compo-

nents that an e-learning system is likely to have. The main components of an e-learning system are depicted in Figures 2 and 3.

The *IAF-Physical perspective on Architecture* separates the various components related to the actual deployment of the system. This view deals with the communication infrastructure and service categories. Service delivery engines, delivery devices and federated digital repositories are the other main components in this perspective.

The *IAF-Functional perspective* on an e-learning system is divided into two different perspectives, the *content perspective* and the *individual perspective*. The content perspective deals with the issues related to the content that is available for learning; these include the repositories, learner's profile management and catalogs. The *Personal perspective* of the functional model deals with issues related to the management of information about the learner.

## JISC E-Learning Framework and E-Framework

The E-learning framework and E-Framework are the initiatives by U.K.'s Joint Informa-

Figure 2. Logical architecture of an e-learning system. (© 2003 IMS Global Learning Consortium. Used with permission. http://www.imsglobal.com)

170

Appendix A: Selected Papers
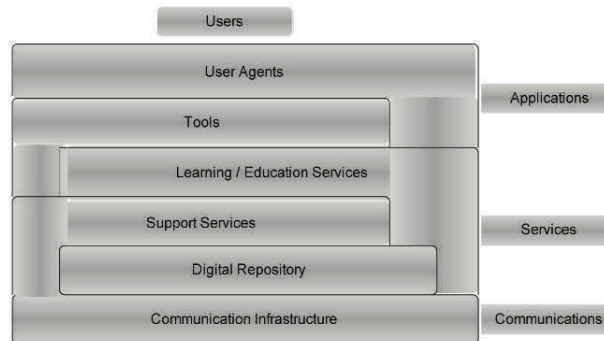
Figure 3. Layers of an e-learning system. (© 2003 IMS Global Learning Consortium. Used with permission. http://www.imsglobal.com)
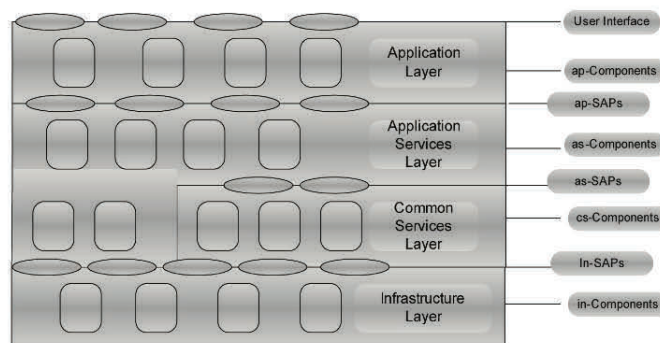
tion Systems Committee (JISC) to produce an evolving and sustainable, open standards based, service oriented technical framework to support the education and research communities (Easterby, 2008). "*The main set of guideline principals of E-framework are service oriented approach to system and process integration, development promotion and adoption of open standards (such as IMS, OASIS, W3C, IEEE), community involvement in development of the e-framework and open collaborative development*" (JISC, 2006).

LSAL E-Learning Services Architecture

The Learning Systems Architecture Lab (LSAL) conducts research focused on the design and creation of Internet-based technologies for education and training. LSAL came up with an E-learning system stack called E-learning Services Architecture (LSAL, 2001) as shown in Figure 4. The whole system is basically divided into three main layers, namely User Agent layer, Learning Services layer and Infrastructure layer.

Sun's E-Learning Framework

A further framework is proposed by SUN Microsystems; Sun's E-learning Framework, which again is broken down into layers. Each layer (tier) performs a critical function within an E-learning system (SUN-ELF, 2003). The major advantage of Sun's framework is its component based approach for faster development, reduced development cost, and security. The framework divides the system into four tiers, namely; *Presentation Tier*, which consists of navigation and presentation logic, *Common Service Tier*, which constitutes the services which are common among the learning application, *E-learning Service Tier*, which consists of components that support the non-learning, delivery-related administration functions, and *Resource Tier*, the assessment system that measures student performance against specific learning goals.

Learning Technology System Architecture (LTSA) IEEE Reference Model

The Learning technology system architecture (LTSA) IEEE Reference model provides a speci-

Figure 4. E-learning system stack (© 2001, Daniel R. Rehak. Used with permission)
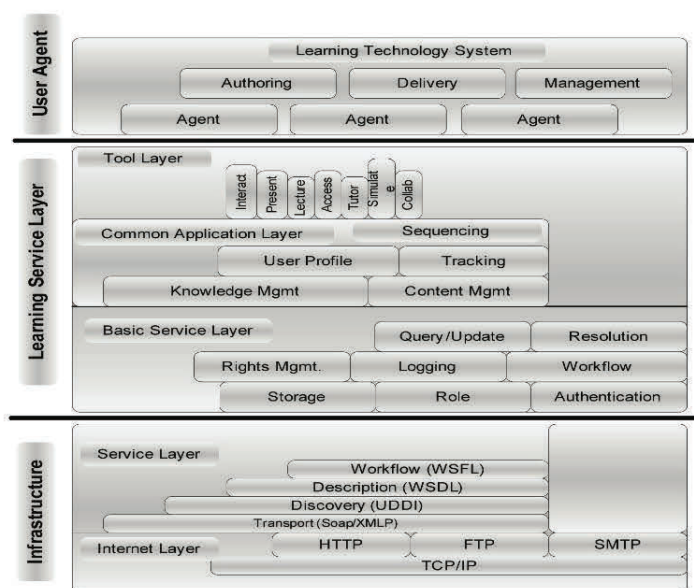
fication for the system design and components for technology supported learning (Farance et al., 1998). Figure 5 present the layers of this architecture. The proposed standard does not focus on the type of technology used for its implementation; furthermore it is also content, pedagogical, and cultural neutral. This conceptual framework:

- Provides guidelines for understanding learning systems
- Underlines the critical interfaces of the systems, thereby allowing for efficient implementation of the system because the common components and interfaces are only implemented once
- Adapts to technology changes because the adaptation is only an incremental change

when viewed at the right level of abstraction, i.e., helping to manage change and reduce technical risk

Open Knowledge Initiative (OKI) Architecture

The Open Knowledge Initiative (OKI) also provides a service based architecture; the main focus is on formal forms of learning, e.g. quizzing, authoring and administration (Kumar et al., 2002). "O.K.I.-based systems should be able to handle the demands of institutions with potentially thousands of faculty, thousands of courses, hundreds of thousands of students, multiple campuses, and students accessing courses from remote locations". Therefore, it is specifically designed to meet the needs

Figure 5. LTSA abstraction-implementation layers (From IEEE Std. 1484.1 1998. Copyright 1998, by IEEE. All rights reserved)
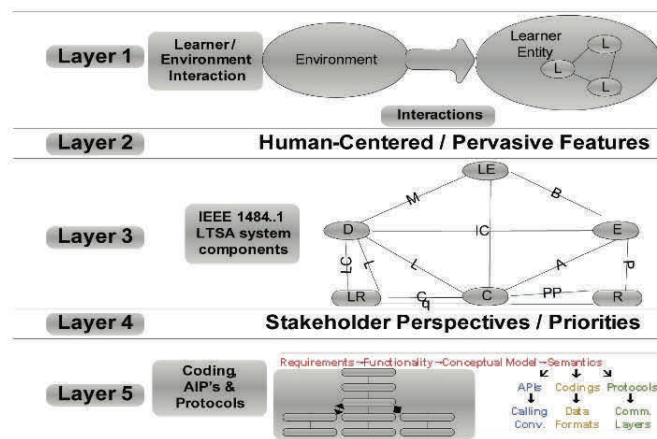
of higher education. The target applications of OKI include amongst others the academic systems, library information systems, central administrative systems, student information systems and digital repositories. It provides application programming interfaces (APIs) to allow the integration of new technologies into the OKI-based systems. A number of APIs have been released by OKI, which are publically available. It follows standards to promote interoperability among learning systems. Figure 6 presents the four different layers of the OKI architecture.

The *Institutional infrastructure layer:* includes the data sources, such as repositories, security servers, file services, and databases which a learning system may use. *Common services layer:* provides common services to applications and provides capabilities to operate over the available data in the institutional infrastructure. *Educational services:* these services allow performing certain tasks related to the educational aspects such as *class ad-* *ministration, assessments and communication services. Educational applications:* consists of tools which are intended to construct different learning applications. These applications use the functionality provided by the services in the lower layers.

OMAF Layered Model

MOBIlearn (OMAF) is a layered abstract model that has been designed and implemented as a service-oriented architecture (Da Bormida et al., 2004). This framework focuses on the interfaces between the learning system layers. It considers explicitly the mobility of the learner. The underlying principle is to follow a user centered design and proposes the conceptual layout of the services to access the learning resources. The MOBIlearn project implements this framework. Figure 7 depicts the layers of OMAF.

- **Mobile meta-applications layer:** Consists of applications and tools which are

173

Appendix A: Selected Papers

Figure 6. OKI architecture for learning management systems (© 2002 Massachusetts Institute of Technology. Used with permission)
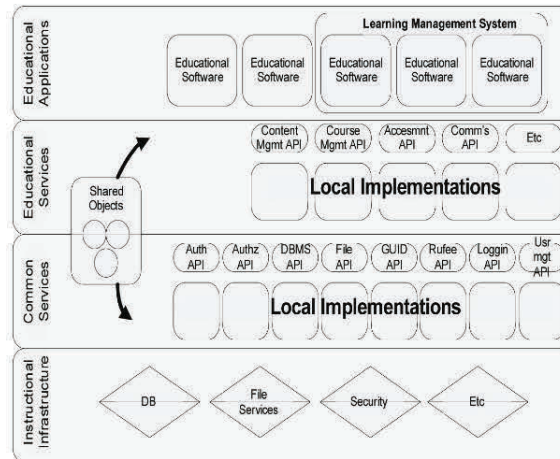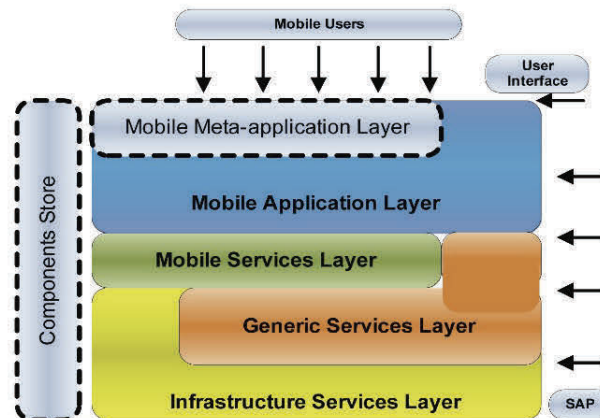

Figure 7. The OMAF layered model (© 2006 MOBIlearn Consortium. Used with permission)

Appendix A: Selected Papers

constructed from two or more mobile applications to support more complicated and extended functionality

- **Mobile applications layer:** These are the applications which are designed and implemented to provide mobile functionality
- **Mobile services layer:** These components provide mobile services to the mobile application layer
- **Generic services layer:** As the name suggest these components provide generic services
- **Infrastructure services layer:** These provide communication, messaging and transaction support
- **Service access points:** These are implemented as interfaces in APIs. Each interface provides access to one service capability
- **Components store:** Provides components to support generic mobile services

Common Aspects of Existing Frameworks

Common Aspects Which Can be Identified After Comparing These Frameworks Are

- Services are always layered over each other; the services in the lower layer provide support to the services above them.
- A digital repository is used to manage (store) the learning contents within the system
- Application services are fine grained services which the user directly interacts with such as quizzes, simulations, etc
- Educational services usually revolve around education administration such as course management, scheduling, etc
- Common services provide the functionality that the user is not directly exposed to, but is essential, such as authentication, file sharing, logging, database management, etc

- The infrastructure consists of the backbone services dealing with HTTP, SOAP, XML, etc

STRENGTHS AND LIMITATIONS OF EXISTING FRAMEWORKS

Measuring the strengths or limitations of a framework is not a trivial task. However, based on the area of application, variables can be identified which influence the adaptation of a framework in a particular application context. In our study the evaluation is focused on informal collaborative aspects of mobile learning situated in a city wide contextual space.

The following variables are identified for our work:

- **Abstract**: An abstract framework is good; however the shortcoming is that it is too general and the scope of application becomes very wide. By abstract we mean a framework which only provides guidelines, but does not provide a concrete implementation of its own
- **Follows standards**: A Framework which follows standards is better than the one that does not follow standards
- **Service oriented**: A services based framework is better than one which is locked into a single functional unit
- **Involves agents**: Involving software agents in the framework allows a software system to participate actively in the learning processes
- **Considers informal learning**: Most of the frameworks consider learning to be a formal activity, such as classroom learning. However, in our work we are more interested in informal learning
- **Contextual aspects of learning**: Aspects such as the nature of the learning activity, the time and the place where the learning happens, greatly affect the learning process when we consider learning in a city wide context

- **Situatedness support**: Certain learning activities can only occur when the learner is situated in a particular environment and is surrounded by a certain set of conditions (e.g. other learners, learning resources, vicinity of historical buildings etc.) A learning framework which considers the aspects of situated learning and provides for its support has advantages over one which does not
- **Concrete services description**: Just informing about the names of the services is not enough, a framework should also suggest the finer details of the learning services; such as the input/out, contextual use of services, pre/post conditions etc.
- **Collaboration support**: While considering mobility of learner in a wide contextual space. Together with the learning services there is also a great need for services to support collaboration between learners. Collaboration support includes things such as taking a combined decision, group discussions, creating an artifact together (document, drawing etc.).

- **Interoperable:** A framework should consider interoperability with other systems
- **Extensible:** A learning framework should allow the extensibility of a learning system. In this regard it should be possible to extend the system with new learning applications. In this way system should be able to support different forms of learning

Figure 8 provides an analysis of the strengths and limitations of frameworks discussed in the previous sections against our chosen variables.

Discussion and Evaluation of Frameworks for FABULA System

All the frameworks discussed in the previous section are intended to be abstract enough to be adaptable to a very wide scope of learning systems. Many of these frameworks are successfully adopted and their actual implementation does exist. However, most of them mainly focus on the delivery of learning content to the learner. There is hardly a framework which

Figure 8. Comparison of existing frameworks

	IAF	LSAL	SUN's E-learning	LTSA	OKI	OMAF
Abstract	Y	Y	N	Y	N	N
Follow standards	Y	N	N	Y	Y	Y
Service oriented	Y	Y	Y	N	Y	Y
Involves agent	P	P	N	Y	N	N
Considers informal learning	N	N	N	N	N	Y
Contextual aspects of learning	P	P	N	Y	N	Y
Situatedness support	P	N	N	P	N	P
Concrete services description	N	N	N	N	Y	Y
Collaboration support	P	Y	Y	P	Y	?
Interoperability	Y	P	Y	P	Y	?
Extensible	Y	P	Y	Y	Y	Y

Legends Y = Yes, N = No, P = Partially

Appendix A: Selected Papers

attempts to support informal learning. Involvement of active entities such as software agents allows the possibility of intelligent behavior of a system. In dynamic settings where learning takes place in a city, such as that addressed by FABULA, A situation may exist where the learner is not sure where to look for more hints for learning, or might be completely unaware of the available possibilities for learning (i.e. other learners, historical buildings) surrounding him/her. Under such conditions the importance of proactive behavior of the learning system is paramount and cannot be neglected. However there is lack of integration of such concepts in the previously discussed frameworks.

Another important feature which is needed in a system which operates in a city wide context is support for collaboration and situatedness. Just having mailing lists and threaded discussions is not enough. Most of the frameworks have limited support and adaptability to the fact that the collaboration needs to take place in real time and must take into account the situated aspects of the learner and the learning activity.

Other evaluation parameters such as interoperability, extensibility and service orientedness are supported by the discussed frameworks in one way or the other.

FABULA SERVICE ARCHITECTURE

As discussed earlier our system uses services as the basic building blocks. In the architecture of FABULA, every component (except software agents) is generalized to be a service. Depicted in Figure 9, services of the complete system are divided into logical layers. This layering is based on the functionality of the service in the system. Each layer consists of different categories of services. Such a layering helps to separate the services in the system based on their role during the system execution. The overall framework is divided into four main layers as shown in Figure 9. Based on the roles of services in the system we can make some differentiation among these services. Therefore, we look at our system from two different perspectives:

- Passive services perspective
- Active services perspective

Figure 9. FABULA service architecture
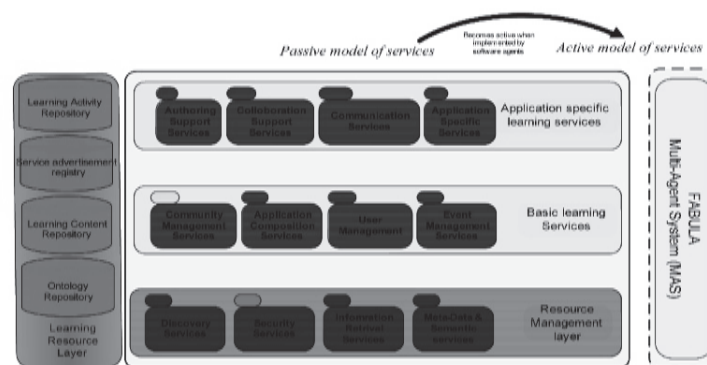
177

While looking at the system from a passive services perspective we consider the system as a collection of functional units (i.e. services). At this stage we are more interested in the type of functionality the system should support. Functionality such as managing the system resources (e.g. user information, learning content etc.), system management and the support for different learning activities. These are the services with associated descriptions (i.e. functional capability), described in some service description language (for automated reasoning), and published in a directory repository. These services can be searched and invoked when needed. To summarize, a passive service is a functional unit of the system, which is described, published, searched when needed and invoked on demand if available.

A passive service becomes an active service when it is hosted by a software agent. The software agent or multi-agent system of FABULA (see the FABULA MULTI-AGENT SYSTEM section) performs the core system functionalities and therefore these can be considered as active components of the system. A software agent is the host of passive services (i.e. when hosted by agent, they become active services). In practical terms a software agent can host many passive FABULA services. Thus, each agent has role(s) which are fulfilled by passive service(s) it hosts. FABULA Multi Agent system (F-MAS) operates at all the layers of the system as can be seen in Figure 9. An agent controls how and when the functionality of the system is accessed. Under certain conditions it can also trigger the functionality in an intelligent/autonomous manner. Each agent acts in a proactive and autonomous fashion to cooperate with other agents in the system to increase the learning outcome. Having the agents operate at all levels allows us to gain finer control over the system's operations. Intelligent behaviors of agents when blended with system functionality can have a direct impact on the learning outcome.

PASSIVE SYSTEM PERSPECTIVE

Based on the nature of their functionality, passive services are organized into three different levels in the system. At these levels services are categorized into twelve main categories. An important thing to mention is the fact that all service categories in the *Basic Learning Services* and *Resource Management Services* are the life line services in our system. In this way these categories are extremely important for the system's execution. While discussing the services in the later subsection we deliberate omit the names of common services and only mention the names of services which may be more interesting for mobile learning.

Application Specific Learning Services Layer

This layer includes the services which have direct influence on the pedagogical features supported by the system. These services allow the users to edit, update and manipulate the learning artifacts. These services are dependent on the learning applications. For example, services required for learning in the classroom environment can be very different from the services required for learning in a museum. In this manner the system can be developed in an incremental fashion, by adding more services when a new application is to be supported by the system. The categories of services in this layer are.

Authoring support services: Include the services which allow users to edit documents (Create, update, delete) and other learning artifacts. The main utility of such services will be during the time when several users are editing a learning artifact. This category of services includes.

- Document editing services (Create, update, delete)

Appendix A: Selected Papers

- Concurrent artifactsediting management services
- Calendar management services

Collaboration support services: Consist of complementary services; these services may never play a direct role in the Learning Application. However these services may be invoked by the user in an ad-hoc manner for collaboration. These services are mainly intended to support the performance of shared tasks, to support social networking, allow users to actively participate in the learning activity and make the learning more visible (Calori & Divitini, 2008). These services include:

- Social network representation to the user
- Place representation (e.g. available users in the learning environment)
- Management & maintenance of social relationships among different learning networks Management of places where learning takes place.

Communication services: These services also consist of complementary services and may never play a direct role in the Learning Application. But they can be invoked by the user in an ad-hoc manner for communication. Communication services include the following:

- Text messaging
- Picture messaging
- Voice communication

Application specific services: These are the services which may be dynamically added to the system (i.e. advertised in the Semantic Service Advertisement Repository). Since we look at FABULA as a system that could be used in many different learning contexts, then for each context different services will be required. Thus, these services will be completely specific to the context of application, and hard to predict. With the addition of such services the system may start to support more learning use-cases or may start to perform better for existing use-cases.

Basic Learning Services Layer

Services at this layer are the intermediate level services, they do not directly interact with the user or directly with the learning content. These services use the functionality of the services in the lower layer and support the services in the upper layer at run time. Accessing or providing functionality to/from all the services in other layers is done through clearly defined *Service Access Points (SAP)* (i.e. Service Interface). Thus, maintaining *autonomy* and *heterogeneity* in the system. These services perform the functionalities which are common to many learning processes.

Community management services: This category of services consists of services related to managing the user community, since FABULA is all about collaboration among its users. These services are vital; the sole purpose of these services is to manage different structures of user communities (see Groups AGORA(GA) in the FABULA multi-agent system section). Services such as recommendations about the social connections and contacts belong to this category.

Application composition services: Services in this category are responsible for constructing the Learning Applications based on user demand.

User management services: Manage the storage, retrieval and search of user profiles.

Event management services: We consider FABULA to be an event driven system. Services in this category consist of services which manage different events within FABULA. The main idea to have such an event based system is due to the fact that FABULA is a distributed services based system, thus there is no possibility of integrated programming style (function calls and exception handling). Events will provide the necessary abstraction to deal with various kinds of flow primitives as needed by Learning Applications or dependencies among service invocations.

Appendix A: Selected Papers

Resource Management Services Layer

This layer provides the most basic system level services for FABULA. These services handle the data that is stored in and accessed from the repositories. Services in this layer are very much static in the system.

Discovery services: Provide information about the other services (basically services in the upper layer) which are available in the system. These services directly operate on the service advertisement repository.

Security services: Category contains all the services related to the security of the system. These services take care of the issues related to the identity and permission management of the user or its agent.

Information retrieval services: This category of services includes the services associated with the content management and retrieval from the content repository. This category include the following services:

*   Service for storing, retrieval, organization and searching the content in the content repository
*   Cataloguing Service
*   Content Archival Service
*   Digital rights management Service
*   Services for content reputation and recommendation (social content filtering and collaborative filtering)

Meta-data and semantic annotation service: This category of services works over the ontology repository. The services in this category are required to do semantic reasoning with the concepts of the FABULA ontology. The learning content saved in the content repositories can be associated with semantic metadata and the ontology can be queried through these services. Services in this category include:

*   Semantic reasoning service
*   Metadata creator service
*   Terminology service
*   Ontology query service

AGORA AS ACTIVE SYSTEM PERSPECTIVE

As discussed earlier, the active service perspective considers the system to be a collection of software agents, hosting different services, communicating and collaborating with one another. Thus, the active perspective takes into account the dynamic aspects of FABULA system at execution time. The complete functionality of agents is illustrated with our pre-existing agent framework called AGORA (Matskin and Kirkeluten 2001, Matskin 1999, Matskin, 1998). The literal meaning of AGORA is an ancient Greek marketplace where people gathered to chat, negotiate and get news. Using AGORA simplifies the capture of all the dynamic behaviors of agents at execution time including communication, coordination and negotiation.

Figure 10 presents a simple AGORA which can be considered as a conceptual node or a meeting point for different agents for cooperative work. For each cooperative work point (act of communication, coordination or negotiation) there can exist an AGORA node.

Figure 10. AGORA node

Appendix A: Selected Papers

The AGORA node provides some default functionalities through *default agents* available in each AGORA. These agents provide the services needed to support the coordination, negotiation and shared activity execution within an AGORA node. Each AGORA node can also contain an arbitrary number of *registered agents;* these agents use the functionality provided by the AGORA node. Registered agents represent participants of cooperative activity and the default agents correspond to the management service providers which are created by default when a new AGORA is generated/created.

The presence of default agents in the AGORA based multi-agent system (MAS) ensures that the architecture of registered agents can be kept simple and oriented towards useful processing. The default agents take care of complex details of enforcing coordination decisions, security checks, negotiations, message interoperability and translation for agent communication in the MAS. In a learning environment AGORA can be viewed as a small *Learning Management System* with a set of learning rules and learning nodes in combination with several services. An AGORA node can create child AGORA nodes if needed to take care of specific communication, coordination or negotiation needs.

Using the AGORA approach to MAS design requires the following steps:

- Understand the problem to be solved and then identify the participants (i.e. registered agents) in the cooperative activity.
- Identify the cooperation point amongst the participant agents (i.e. registered agents)
- Once the cooperation points are identified; the next step is to detail the kind of communication, coordination or negotiation participant agents may require from the default AGORA agents
- Finally, realize the participant agents and AGORAs

FABULA MULTI-AGENT SYSTEM (F-MAS)

The FABULA Multi-agent system (F-MAS) is built on our existing work in the FABULA project (Khan and Matskin 2009, Kathayat and Khan 2009). It consists of several different agents. Each agent performs (or participates in) specific system functionalities. As depicted in Figure 11, F-MAS aims to support the domain (city-wide collaborative learning) as directly as possible. It also aims to support the cross-cutting aspects (awareness, interruption, documentation and reflection) of the FABULA design space (Calori et al., in press) considering both the active and passive nature of domain (or system) entities.

The real benefit achieved by the multi-agent system is the intelligent operations to achieve better learning outcomes. The main application areas where the multi-agent system performs its functions are community management, context awareness, content filtering/provision and other proactive system behaviors such as offline processing, learning user's preferences etc. All the services and functionality of agents in the system are mapped to a respective AGORA node. The AGORAs of F-MAS are divided into two main categories. These categorizations are based on their nature/functionalities in FABULA application areas. The two main categories are the *application AGORAs layer* and *manager AGORAs layer*.

The functionality (or behavior) of AGORAs in the *application AGORA layer* may change (be extended) according the nature and context of the FABULA application (services), whereas the FABULA system manager AGORAs represent the more static part of F-MAS. We believe that certain functionality of agents in the *application AGORA layer* could be very similar to each other. This is to say that each AGORA in the *application AGORA layer* contains some generic behaviors. Generic parts may include coordination, adaptation, and configuration mechanisms among or within the AGORAs.

181

Appendix A: Selected Papers

Figure 11. FABULA multi-agent system architecture
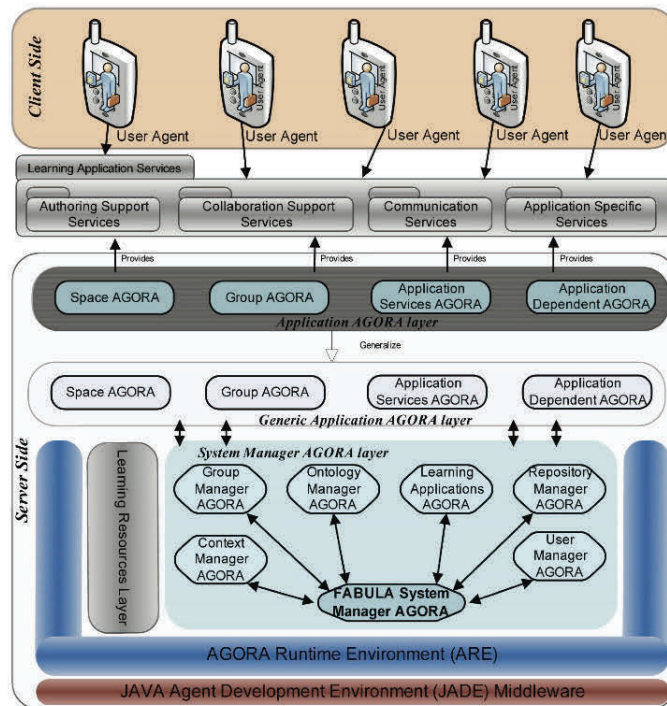
A third diminutive category of agents called *User Agents* (UA) also exists in the system. These agents are not implemented as AGORAs, instead they connect to the *application layer AGORAs* as registered agents and use the functional capabilities of the system through the services provided by *application layer AGORAs*.

Application AGORAs

Several instances of *Application AGORAs* can exist in the system. The design and functionality of such AGORAs are defined for each application differently. Even within the same application, the behavior of the *application AGORA(s)* may vary depending on different contexts and configurations. Thus, these AGORAs will integrate the domain concepts of the application they are used in. These AGORAs are provided as generic templates, which already contain the basic and important functionalities. However, if needed, they can be extended and/or overridden to support more complex functionalities. The following AGORAs are identified in this category.

Appendix A: Selected Papers

Groups AGORA (GA): Represent sets of learners grouped together in a logical structure. This kind of AGORA takes care of the communication of *User Agents* (UA) with other UA[s] within the learning group and with other learning groups. We believe that the "*most interesting learning scenarios are those that provide a high degree of situatedness with respect to the social structure and the space where learning experiences take place*" (Calori and Divitini 2008). Different types of groups can exist in the system, each supporting a particular form of social structure. Maintaining these social structures has different requirements on the strategies of communication, coordination and management within the groups. Our system supports five different forms of such structures (Calori. 2008).

- Community of practice
- Learning ecologies
- Micorrhizae
- Smart mobs
- Social world as locales framework

For supporting each of the above structures, group AGORAs with different behaviors exist in the system, each specializing in the type of group it supports. These AGORAs ensure the proper representation, management and organization of the social structures.

Space AGORA (SA): People's interactions and social relations are highly local, grounded in and organized around physical spaces. In such a situation contextual information may not be the only information needed by the learner. The space agent in FABULA represents the space of the users during a learning application. The space can play an active role by imposing certain constraints on user's actions in a given condition. It can also play a passive role by informing about the services available in the surroundings of the user (Calori et al., in press). The space AGORA is therefore an integral entity of the system which can take certain initiatives, or can behave proactively based on changes in the properties of the user's space.

Application Services AGORA (ASA): The application AGORA takes care of two important issues. First, in a ubiquitous environment, objects and spaces might be augmented with computational capabilities. This increases the number of service providers. For example, a service might be provided directly by a learning object associated with a physical artifact in the city. Second, learning scenarios where learning comes from exploration, interaction and serendipity are characterized by dynamic and emerging learning experiences (Calori, 2009). This implies that the services that are needed might not always be defined a-priori. Though a certain constellation of services might function well at a certain point in time, it might not necessarily be able to evolve. Finding and invoking all the required services might not be possible for the user agents (UAs) or group AGORAs (GAs). The main role of the ASA is to locate and invoke such services, which are relevant for a learning application. It assists the UA and GA to find and invoke different services of FABULA.

Application dependent AGORA: Depending on the application at hand, the FABULA system can contain other application dependent AGORAs. Different types of application learning objects (or AGORA) fall under this category. As discussed later in the treasure hunt application, the Inter-group AGORA in the treasure hunt game-based learning scenario is an example.

User Agent (UA)

The user agent represents the one who uses the system, for example students (or learning peers in general). This agent encapsulates important features of mobile learning, both pedagogical and technical. This agent is located locally at the mobile device of the user and interacts with the other agents on behalf of its user. However, if the user is carrying a mobile device with limited capabilities, this agent can run on the server-side on behalf of its user. It learns the preferences of the learner such as:

Appendix A: Selected Papers

- Topics the learner is interested to learn about
- Subjects the learner is skilled in
- Times when learner is interested in participating in a mobile learning activity in a city
- Prompting its learner when another learner who matches their interests is close by in the city (providing awareness information and allowing for transaction from awareness to interaction)
- Blocking incoming participation requests or hiding the presence of its user when the learner is busy and does not want to be disturbed (Controlling the nimbus (Rodden, 1996))

It also understands the parameters in its user's profile. Such parameters may include:

- The age of the user
- The language(s) the user understands
- The types of learning activities the user likes to engage in

It also performs certain functions intelligently for its user, such as:

- Recommending and providing learning content to its user, based on the ongoing learning activity
- Allowing off-line processing
- Social network building
- Giving directions and hints during learning activities

It allows the system behavior to adapt according to its user. Apart from the basic functionality, the user agent integrates and understands the domain concepts of the application it is being used in.

System Manager AGORAs

The FABULA system manager AGORAs represent a more static part of the FABULA system. Only one instance of these AGORAs exists in the system. Each AGORA in this category takes care of core system functionality. AGORAs in this category are static in their nature, this is to say that the functionality of these AGORAs will not change for different FABULA applications. This includes the coordination strategies among the AGORAs, supporting adaptation to different contextual spaces and accordingly configuring other AGORAs and their capabilities. Thus, they provide a platform for supporting different FABULA applications.

FABULA Manager AGORA (FMA): Is the system AGORA which takes care of the overall system functionality; it acts as a supervisor for other manager AGORAs in FABULA.

User Manager *AGORA* (UMA): Is the manager AGORA, which takes care of the user agents (UA) in FABULA. Although group structures and internal communications of groups are managed by GA at application level, however at system level overall group management is the responsibility of the *Groups Manager AGORA (GMA)*. This AGORA creates, destroys and maintains the groups in the system, and all GAs are under direct control of the GMA. Besides that, GMA also assists and supports the group related functionalities for the users.

A manager AGORA called the *Repository Manager AGORA (RMA)* takes care of the content in a FABULA repository. Any learning system cannot be considered in isolation of the learning content it provides to its learner. The intelligence and utility of RMA lies in the fact that it understands and manipulates the semantic relationships among the FABULA content. It entertains all the content queries.

Ontology Manager AGORA (OMA): Takes care of the FABULA ontology. This AGORA is also associated with a repository (i.e. Ontology repository). It manages all the relationships among the FABULA concepts.

FABULA Space Manager *AGORA* (SMA): Is mainly responsible for understanding all the parameters related to the user's learning space. In our work we consider that there can exist different learning spaces in the city. This manager AGORA aggregates all the information related to the learning spaces and

Appendix A: Selected Papers

provides this information to other system entities when needed, so they can adapt the system behavior according to the learning space. It is also responsible for the management and life cycle activities of space AGORA (SA).

FABULA Context Manager *AGORA* **(CMA):** Is responsible for managing the contextual information during the learning activity. The contextual information includes the physical, temporal and learning activity related parameters.

EXAMPLE OF AGORA BASED TREASURE HUNT GAME

New students have just arrived in a city to attend university for this semester. They are interested in learning by exploring different places of interest in and around the city, e.g. historical buildings, museums, and parks. A learning activity called *Treasure Hunt Game* is made available in the city through a FABULA system. This service allows users to logon and explore the city using their handheld devices. Users can also specify their interests, and preferences. The *Treasure Hunt Game* revolves around treasures; these treasures are hidden at different places in the surroundings of the city. Each treasure can have a number of clues associated with it, and these clues contain the information about the location of treasures. These treasures are arranged in sequential order; only after finding the first treasure can students search for the next treasure. In order to get the information hidden in the clue students have to use their common/general knowledge. In doing so, students have to collaborate with each other.

When a user is connected to a FABULA system, their location information is continuously and automatically updated in the system. The system responds to these updates by informing UA about other closely located users having similar interests. Users may create social groups and invite others to join groups. Users are also able to see other members of their groups on the map and can communicate

with them via instant messaging, group chat, and group discussions.

Use case: Ten students who were wondering around the city are sensed by the system. Based on their preferences, the system has identified that most of them are interested in learning about the city's historical places and buildings. The system sends a text message to their mobile devices, asking them if they are interested in playing the game. The users agree to play the game.

In the next phase, the system divides students into groups and informs them about their groups. For our scenario, students are divided into two groups, consisting of five students in each group; this grouping is based on the location of students. The students who have lesser distance between them are put into one group. Different clues and treasures are already in place, and the system dynamically and intelligently combines them to create games for each group. At the start of the game groups are informed about the first clues to begin the game. The system continuously infiltrates the learning activity, by providing the participants of the game with useful advice and thus helps them during their learning activity.

Designing the F-MAS

By simple inspection we can identify that there are ten participants in our *Treasure Hunt Game*. As discussed earlier all participants in the learning activity are represented in the system by their *user agents* (UA). Based on this information we create an *active perspective* for our example, where the following can be identified:

- **Ten User Agents (as Registered Agents):** Representing the users.
- **Two Group AGORA:** Managing the representation of social networks and the management of activities within the groups.
- **Application Services AGORA:** Will also be created for each learning group, it provides services which are needed for the group during communication and

185

Appendix A: Selected Papers

coordination. The majority of services will come from the Application Specific Learning Service Layer.

- **A Space AGORA:** Is also created for each learning group. It the mainly responsible for collecting and providing information related to the contextual space of the learner. Location, position and context information of the users allow the other system entities to adapt the system behavior according to the factors surroundings the user such as the other learners, position, time and available services in that location.

- Another type of AGORA which implicitly exists in this scenario is the **Intergroup AGORA**. This AGORA is a subtype of "application dependent AGORA". Such a collaboration node is required when students from one group wants to communicate with students in another group. In this case AGORA will impose rules of group-to-group communication and coordination (i.e. Intergroup). This AGORA

will also provide the possibilities for merging the two different groups to form one group, thus allowing the groups to evolve.

The active perspective for this example is shown in Figure 12.

Detailed Processing of AGORA Based System

Assuming that the users already have a user agent running on their mobile devices (i.e. users have downloaded the FABULA application onto their mobile devices), then based on the position of users in the city and the buildings in their vicinity, the system creates games for each of the groups. Once a learning application (i.e. game) is created the system invites the students to start the treasure hunt game.

- **Case 1-User Agent at Work:** During the learning activity the learner is discussing a building with other learners. The user

Figure 12. Example of active perspective
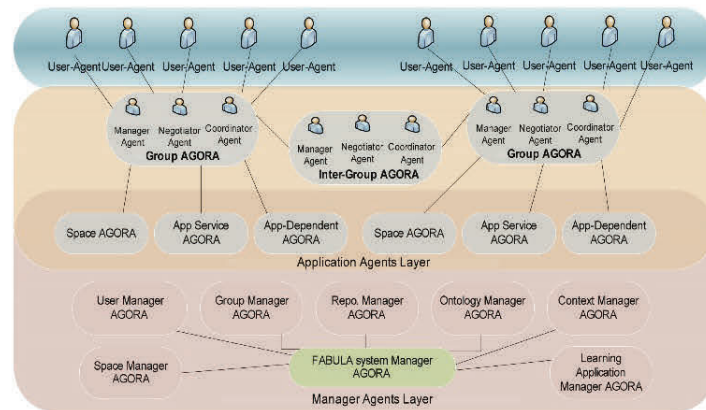
Appendix A: Selected Papers

agent performs continuous analysis on the incoming and outgoing chat messages. Once it identifies that a building is being discussed by its learner, the user agent searches information about the building and provides it to the user; also it provides the learner with other suggestions relevant to the building. While searching for treasures in the city, a learner is no longer in the range of a wireless network, but s/he is still sending messages to group members and editing a shared document. In this case the user agent queues the messages to be sent and changes to be committed. As soon as the network becomes available again the queued operations are executed.

- **Case 2-Group AGORA at Work:** During the learning activity a learner finds a clue about the treasure his/her group is searching for. The learner writes the information in a text message and instructs their user agent to broadcast it to the whole group. In this case the user agent hands over the message to the group AGORA which ensures the delivery of this message. In the group the learners need to answer a question and none of them knows the exact answer. Group AGORA provides support to make a group decision (this involves communicating with other agents to invoke the appropriate service, such as voting).

- **Case 3-Application Services Agent at Work:** A building provides some services, providing information about the building (maps, historical importance and architectural highlights etc.), and another service which can collect the comments from the learners who are visiting or have visited the building. These services were not known prior. The application services AGORA collects the information about these newly available services and informs the user agent about their availability. Under a special situation a learner wants to update his/her learning preferences in his/her profile. Such services are

not available to the learner on the mobile device as such services are not commonly invoked for learning. However the application services AGORA can interact with the manager AGORAs and can make such services available to the learner. Some services are created only as a part of certain learning application. Such as the treasure service in a treasure hunt game. It is therefore also the job of application services AGORA to maintain the information about how to invoke these services.

- **Case 4-Space AGORA at Work:** During the learning activity, the position of each learner in the group can be very useful for the group and for the system. Two different learners can avoid visiting the same place to find a treasure. The system can also use the position information to adapt the system behaviors (e.g. high data rates might not be an option at a certain points in the city). It is the responsibility of the space AGORA to provide, collect and distribute this information. Positioning information is also used by the space manager AGORA and the context manager AGORA to evaluate contextual and spatial factors surrounding the learner, such as weather, traffic situation, nature of learning activity and time. Based on this information the Space manager AGORA also decides which services should be available in certain spaces and which should not (rules and tools).

- **Case 5-AGORA as control unit:** Students within a group decide to share the work load of an activity. AGORA insures that every student provides some input to get access to the other's output. If two groups decide to share information about their treasures, AGORA ensures that both the groups provide such information. A certain game might follow a special pattern of communication among the learners. AGORA ensures that this pattern is followed.

Appendix A: Selected Papers

Implementation Features

For the implementation of our work we are using JADE (Java Agent Development Environment) (Bellifemine et al 2007) as the middleware layer for our agent based software development. JADE is fully FIPA (FIPA 2000) compliant agent development environment. The AGORA system uses the services provided by JADE; however instead of creating simple JADE agents the AGORA runtime system provides the support for creating AGORAs. Each agent of AGORA is an extended version simple JADE agent. The internal models of Manager, Coordinator and Negotiator agents are different. A Manager is constructed to be simple reactive agent, whereas the Coordinator and Negotiator agents are intelligent agents. We are using Drools (Browne, 2009; Bali, 2009) as the rules engine for Negotiator and Coordinator agents, each incorporating an internal knowledge base. From this point of view each AGORA can be programmed to be a small expert system, each focused on dealing with certain types of learning support situation. Since we have emphasized the fact that active/intelligent support is required for city wide collaborative learning, in order to support such system operations all the actions and services of agents are described using an ontology. The other aspects related to learning in the city are also part of this ontology. Concepts of this ontology are use as the content of agent communication messages. From an implementation point of view the FABULA system can be considered as a large distributed system, where the resources (i.e. services of the system and learning resources) are distributed. Therefore, in order to search and invoke a service, all the AGORAs are organized in a P2P fashion. Using the Chord algorithm as a first step the network of all the AGORAs in the system can be also considered as a distributed service repository. In the future we intend to extend our system for semantic resource/service discover and learning application composition.

FABULA FRAMEWORK IN COMPARISON TO EXISTING WORK

The core novelty of our work lies in the active participation of the system in a learning process and the inclusion of pedagogical aspects in the early system design. The proactive nature of our system allows it to trigger actions intelligently. This is achieved by introducing software agents at each layer of the system's functionality. These agents are not just for technical purposes, but their concept and functions are directly mapped from the pedagogical support they are intended to provide. In this way there is a clear separation between the functionality the system can perform and the intelligence required for performing it. Some existing work does use software agents, but only partially, not for complete system architecture. In these works, only the *User Agent* is considered to be a part of the system.

Another important aspect of our system is its support for spontaneous and ad-hoc forms of learning in a city. Most of the existing work mainly considers the formal form of learning, which happens as a planned activity and the main aim is to deliver the learning content to the user. In our case we focus on support the learning that occurs as the result of serendipitous interaction and exploration.

CONCLUSION AND FUTURE WORK

This article has outlined a framework for learning which happens in the environments which were previously not considered by learning support systems. Not only is the environment different; the forms of learning and used modalities are also very different. The focus of our system is not just to deliver the content to the learner, but to support collaboration, cooperation and knowledge sharing. For this purpose we attempted to combine the pedagogical and technological dimension in our system. Furthermore our system uses services for supporting

Appendix A: Selected Papers

e-learning, but our focus is not just to specify the interfaces of services, instead we are more interested to make these services more valuable to the users. In order to simplify the complete technical architecture of the FABULA system and to pay due attention to every important aspect of the system, the complete system has been looked at from two different perspectives. The passive system perspective has identified and categorized the main set of services required in the system. The active perspective of the system highlighted the type of intelligent operations needed to be performed by such systems.

In this article we have outlined the main components of our system. The service model presented in this article has already been implemented using another multi-agent system methodology. We have extended the AGORA framework, and implemented a service discover mechanism in a P2P fashion the system, with android based mobile devices to connect to our system from the network available in the city. With the current implementation, only functional testing has been undertaken so far. User evaluation will be performed in a series of stages to assess various concepts; use in a city-wide context, ontologies for city wide learning, utility functions of agents to increase the learning outcomes, service discovery and learning application composition.

Our future work is focused on further refinement of the system architecture. An ontology of the concepts is extracted from the work presented above and is being used in F-MAS. Our work also focuses on the identification of situations in e-learning where the intelligent support from multi-agent system may be useful.

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Appendix A: Selected Papers

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A 2. Source of Paper P3

A 3. Source of Paper P4

Appendix A: Selected Papers

A 4. Source of Paper P6

Multiagent system to support Place/Space based mobile learning in city

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Abstract— **Different approaches have been developed to provide technical support for mobile learning. Most these approaches consider only the physical properties of learning environment. In this work, we not only just focus on the physical/spatial dimension of the learning environment of the city, but also pay attention to the notion of Place which is a meaningful outcome of peoples understanding of Space. This paper illustrates how a theoretical conceptualization of *Spaces* and *Places* is mapped into a multi-agent framework called AGORA. It presents the design aspects of a mobile learning system, which uses software agents as its core functional units. We discuss how the theoretical concepts are used to define a technical solution to support mobile learning in a citywide context.**

Keywords-Mobile learning; Multiagent Systems; Mapping; Places; Spaces; Expreince

I.   Introduction

The work presented in this paper highlights our approach to apply multi-agent system for supporting mobile learning in a city. According to [1] "*Mobile learning is any sort of learning that happens when the learner is not at a fixed predetermined location, or learning that happens when the learner takes advantage of the learning opportunities offered by mobile technologies*". In this work we mainly focus on informal form of mobile learning, which takes place in citywide context. Our goal is to provide support to a learner(s) who goes to a city with a mobile device to learn about the city by being in the city (i.e. situated learning). For provisioning such support for learning there needs to be a technical solution which can proactively communicate with the learner to provide automated support for different learning activities. We primarily use Casey's [2], [3]framework of *Place/Space (see section II.A)* to divide and understand city as a collection of different learning locations. The framework provides us with an analytic lens to look at the city from different viewpoints and to construct an understanding about the organization of locations within a city.

We first divide the city into a number of smaller learning areas or *Spaces (as it is used in the Place/Space framework). Space* mainly deals with the physical aspects of learning location. We further divide the *Spaces* into different categories based on their characteristics. Logical structure called *Place* is emulated

over the *Space*. *Places* are constructed based on the learning experiences of the learner(s). Learning experience consists of different factors which were prevailing when a learner previously visited a *Place*. Instead of just focusing on the spatial organization of the learning environment, we stress on the notion of *Place*. *Place* is a dynamic concept and its meaning is reconstructed and renegotiated among its occupants. The understanding developed by applying the framework of *Place/Space* is mapped into a multi-agent framework called **AG**ent **O**riented **R**esource m**A**nagement (AGORA) [4-6]. The static and dynamic nature of *Space*s and *Places* respectively are captured into the behaviors of the multi-agents. The work presented in this paper is conducted in the context of project FABULA [5] and is the continuation of our previous work [7].

The rest of this paper is organized as follows. Next section provides an introduction to different frameworks which we have used in our work. Then we discuss the mapping of *Place/Space* framework to AGROA multi-agent framework. "Related Work" section provides an overview of the similar works. Finally the last section concludes and summarizes the benefits of our approach.

II.   Related Frameworks

A.   Framework of Places/Spaces

The differentiation between *Place* and *Space* serves as an analytical tool to understand the collaborative learning activities [8-10]. Our understanding of this differentiation is based mainly on Casey's [2], [3] explanation of *Place* and *Space* (i.e. the Place/Space Framework). While *Space* mainly relates to the physical aspects of a learning environment and is static in it's nature. *Place* relates to the logical structure and relationships between people's experience and activities in *Space*. *Space relates to the physical world, Place is Space invested with values and meanings* [12].

1)   Space

Space is the physical structure of an area (i.e. learning environment), which consists of geographical coordinates of a piece of land, the interesting objects which are available in the area and the technological services which are available within

the area. For example, church, university, museum are three different *Spaces* having some geographical boundaries.

2) Place

Place is a many sided concept. It is a logical structure, which appears as a logical overlay on *Space*. *Places* can be considered as a *Space* attributed with meanings. A *Place* is therefore a location with attached meaning. The major assumption of the framework is that the nomadic activities (i.e. activities with no permanent location) do not take place in a vacuum. Instead the activities occur in a *Place*, which consists of other individuals present in that *Place*: *"A given Place takes on the properties of its occupants, reflecting these qualities in its own construction and description, and expressing them in its occurrence as an event: places not only are, they happen"* [2].

An individual develops a personal experience of a *Place* when [s]he engages in an activity while visiting a *Place*. Individual's experience of a *Place* influences the future experiences of that and other individual(s) of the same *Place*. Through these experiences *Place* evolves and it's understanding is renegotiated every time a person visits the *Place*.

a) Dynamic and emergent nature of Place: Several *Places* may exist over a single Space; Fig 1 depicts the relationship between *Space* and *Place*. Each *Place* inherits it's attributes and behavioral patterns from the previous experiences and activities of individuals in that *Place*. Thus, a *Place* is an outcome of how different individuals have understood/experienced it over time. It is not only the *Place* that is influenced by expreince of individuals but the inverse is also the case. Thus, on one hand *Place* is influenced by experiences and activities, while on the other hand experiences are influenced by structure of *Place*.
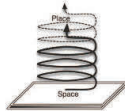

Figure 1. Relationship between Space and Place [7]

Movement inside Place: Movements of individual also add to the dynamic nature of Place. Chasey proposes the following three different kinds of movements of individuals inside a *Place*: . **1) Staying inside Place, 2) Moving inside a Place and 3) Moving between Places.**

B. Framework of Experience

Places emerge mainly through experience of individuals. Chasey [2], [3] suggest a four dimensional model to understand individual's experience in a *Place*. However, in our work we are interested not only in individual's experience

of a *Place*, but also in experience that happens through using supporting technology. Consequently understanding experience only from the point of view of *Place* would be too limited for us. Therefore, we also consider the McCarthy's and Wright's [13], [14] perspective of technology as an experience.

1) Experiencing a Place

According to Chasey, *Places* can be experienced by an individual alongside four different dimensions.

- Psychological Dimension: relates to individual's personal memories, thoughts and believes

- Physical Dimension: is how the physical structure (i.e. Space) of a *Place* supports or hinders the activity the individual is doing in a *Place*

- Historical Dimension: is related to individual's past memories of a *Place*

- Social Dimension: is about the presence of other individual in a *Place*

2) Technology as experience of Individual

McCarthy and Wright's framework of experience targets individual's experience from the perspective of technology. Thus, experience is not an isolated feeling, but it is created about a technological artifact through the use of that artifact. The framework is characterized by four intertwined threads and six sense making processes.

a) Compositional Thread: how experience is constructed and how different parts of expreince fit together to form a coherent whole. *"Referes to the narrative structure, action possibility, plausability, consequences and explanations of actions"[8].*

b) Sensual Thread: how overall design of the environment makes us feel. This includes, but not limited to the social configuration, look and feel of the environment.

c) Emotional Thread: relates to the emotions resulting by using the technology (e.g. joy or faustration)

d) Spatiotemporal Thread: concers how place and time effects expreince.

e) Six Sense making processes: these are reflexive and recursive processes through which people actively make sence of their expreince. These are *1)Anticipating:* prejudice about technology. *2)Connecting:* accounts for the immediate understanding which is developed very quickly when we first look at a technological artifact. *3)Interpreting:* is about associateing meaning to current situation. *4)Reflecting:* Deciding or making judgement about what is possible/impossible/difficult/easy by using an application. *5)Appropriating:* how new expreince fits with our previous expreinces . *6)Recounting:* a dialogical process through which we tell others and ourself about our expreince.

C. Introduction to AGORA Framework

AGORA[4-6] is a multi-agent framework to support cooperative work in open environments. The framework is based on the metaphor of marketplace, which consists of several entities *(software agents in our case)* cooperatively working together to solve a problem. The marketplace provides different supporting services such as coordination, negotiation and management for conducting cooperative activities.
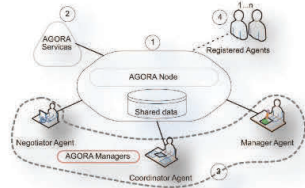

Figure 2: Conceptual structure of an AGORA[4]

Fig 2 depicts the conceptual structure of an AGORA. Each AGORA consists of the following components:
1) AGORA Node: Consists of data which is shared among the manager Agent of the AGORA. **2) AGORA Services:** An AGORA can provide an arbitrary number of services to other AGORAs. These services define the kind and nature of AGORA. Example of services could be a transaction service, credit check service, payment verification service etc. **3) AGORA Managers:** Three different kind of default manager agent are present in every AGORA. *Coordinator Manager Agent* is responsible for providing coordination support during the operation of AGORA. *Negotiator Manager Agent* is responsible for providing negotiation support if conflict occurs during the processing of AGORA. Lastly an *AGORA Manager Agent* is responsible for managing the over all functionality of AGORA. This agent is responsible for hosting AGORA services and other management support such as registering/unregistering the external agents (i.e. Registered Agent). **4) Registered Agents:** These are external agents who register with AGORA to use the functionality provided by the AGORA. An external agent can register with as many AGORAs as it needs and can use the functionality provided by all those AGORA.

AGORA framework supports two different kinds of relationships between AGORAs. The parent-child relationship is established when an AGORA starts another AGORA. The newly created AGORA is the child AGORA of the AGORA starting it (i.e. parent AGORA). This results in a **parent-child network of AGORAs** which acts as a static repository of services provided by AGORA. Different AGORAs can register with each other to share their services. Such dynamic network of AGORAs is called **registration network of AGORAs.** Such a network allows different AGORAs to connect to each other to solve a particular problem in a distributed fashion; which was not possible for an AGORA to solve alone.

III. DESIGN AND MAPPING OF THEORIES TO AGORA

Three different aspects (Space, Place and Expreince) from the theories are mapped to AGORA multi-agent system.

A. Mapping of Learning Experience

Mapping framework for understanding **Experience** to a multi-agent framework such as AGORA in not a straightforward task. This is because of the fact that not every descriptive and narrative aspect of a theory or framework can be translated to a technical solution. For example a dialogical process that occurs inside individual's head cannot be translated to a technical service. Therefore, in our process of mapping *Place/Space* theory and framework of Experience to AGORA we have divided the attributes into **translatable** and **non-translatable**.

As already discussed in previous section we consider Chasey's and McCarthy's explanation of experience in our work. Both Chasey's and McCarthy's explanations of experience are partially overlapping and complementing, but never contradicting. Some aspects, which are missing in one of them are present in the other. Therefore we consider combination of both, while treating intersectional aspects as equivalent. Fig 3 shows the intersectional part of Casey's and McCarthy's understanding of experience. *Psychological experience* from Casey's work is closely related to *Sensual, Emotional* threads and *sense making process of reflecting* in McCarthy's framework. Also the *physical experience* from Casey's explanation of experience is related to *spaito-temporal thread*. We regard five out of six sense-making processes together with Compositional thread from McCarthay framework of experience as non-translatable.
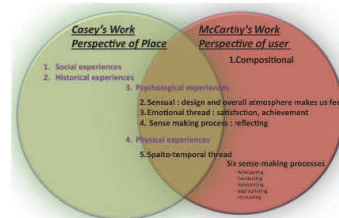

Figure 3. Intersection of Casey's and McCarthy's understanding of experience

Taking into account the metaphor of *Place* as an event we regard the outcome of this event as an **episode of experience**. Every time a user visits a *Place* an episode of experience is constructed as a result of his/her visit to that *Place*. An episode of experience consists of the following translatable attributes from the theory:

1) *Social Experience*: considers the number of users who were present in the *Place*

2) *Historical Experience:* consists of all the previous episodes of user experience of a particular *Place*

3) *Psychological Experience:* consists of overall design impression of the mobile application. This includes user's level (i.e. ranking) of achievement after engaging in mobile learning activity through the use of mobile application and the results of the questions asked from the user to let him/her reflect on the learning activity.

4) *Physical Experience:* The time and *Place* when/where the experience occurred. The duration of experience revels it's significance. For example if a learner has spent only 10 mins visiting a *Place*, while the *Place* requires at least 3 hours for visit, then the expreince epicode may not be very significant.

B. Learner's management in AGORA

In our technological framework a learner is represented by an external software agent who resides in mobile device of the learner. When the learner enters into the boundries of a Space, the software agent of the learner registers with the Space-AGORA of that Space. The software agent of the learner communicates with the Space AGORA and provides the previous episodes of learning expreinces to the Space AGORA. As the learner moves from one Space to another the software agent represnting the learner manages the registration and unregistration for it's learner. GPS is used to know the learner's postion and WiFi networking cababilities are used for communication between, software agents and "FABULA application server".

C. Spaces in AGORA

As it was explained earlier, *Space* is a geographical structure which occupies a physical area. From theoretical point of view *Space* is static and does not changes. For the purpose of modeling Space in our work we consider that a Space consists of four geographical coordinates; these coordinates define the boundaries of a *Space*. Fig 4 depicts the model of *Space*. Along with geographical boundaries a *Space* has an associated textual description.
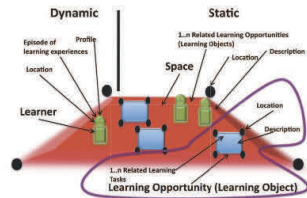

Figure 4: Structure of Space

When position of a learner is with in the boundaries of a *Space*, the learner is considered to be visiting the *Place* associated with boundaries of that *Space*. Interesting *Spaces*

are usually not empty, but consist of different object. A historical monument, tombstone and similar are examples of objects of interest within a *Space*. We call these object **Learning Opportunities** with associated **Learning tasks (multiple choice questions).** A "learning opportunity" also occupies certain area identified by its geographical points within a *Space's* boundary. A dynamic aspect of *Space* is the movement of learners in and out of *Space*. Therefore, we extend the theoretical conceptualization of *Space*, by introducing a modification that the presence/availability of learners is a dynamic aspect of *Space*. Thus, as the learners come and go in a *Space* the amount of available learning resource within *Space* changes dynamically.

Assuming that a city consists of several *Spaces* spread over it's geographical area. These *Spaces* can be categorized into different categories based on the kind of activities they are used or popular for, each *Space* can belong to one or more of these categories. We consider four different kinds of *Spaces*. They are ***Cultural Spaces, Religious Spaces, Historical Spaces, and Site seeing Spaces***; each category includes and represents the related aspect (i.e. cultural, historical, religious and site seeing) of the city. For example, a church is obviously a religious *Space*, however church might also be a historical and sightseeing *Space*.
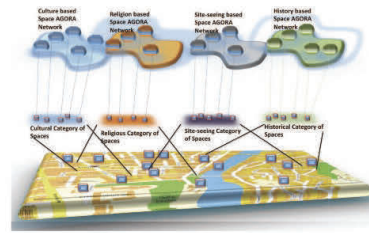

Figure 5: Mapping of AGORAs to catagories of Spaces

Fig 5 depicts this situation. On the map of a city (Trondheim in our case) several different *Spaces* which exist in the city are depicted as small square boxes on the map. *Spaces* in the city are categorized into four different categories. A *Space* can belong to more than one category. A "***Space*-AGORA**" is associated with each *Space* in every category, thus there can be more than one *Space*-AGORA associated with a single *Space*, where each *Space*-AGORA represents a certain aspect of it's associated *Space*. Space-AGORAs are created once in the system and they stay in the system as long as the system runs. *Space*-AGORA acts as a repository of information about its *Space* by keeping the descriptive information about the *Space*. The history of learning activities which have taken place and the comments which user left about the "Learning opportunities" are also kept and managed by *Space*-AGORA. *Space*-AGORA also manages the movement of learner in *Space* and the

functionality related to geographical coordinates information about the *Space* and "Learning Opportunities" in the *Space*. Previous episodes of learning are retrieved by *Space*-AGORA as soon as the software agent of the learner registers with the *Space*-AGORA. *Place* creation as we shall see later, is also the responsibility of the *Space*-AGORA.

D. Places in AGORA

Place is a logical structure which is constructed by combining and reasoning with the previous episodes of learning experiences if they exist. However, if there are no previous learning episodes then the *Place* is created with default configurations. The level of abstraction adopted by *Place/Space* framework does not put any constraint on the size of *Spaces* over which the *Places* are created. From theoretical point of view *Spaces* (transitively Places as well) are elastic concepts and the size of *Space* and *Place* can vary. However as discussed previously we put a limit on the size of *Space* by defining the geographical boundaries of the *Space*. In order to overcome this limitation and to allow size of *Places* to grow and shrink based on user's need. We consider two different kinds of *Places*; namely **Static Place** and **dynamic Place**. Furthermore, centered around the number of learners who visit the *Place*; static type of *Places* are further subdivided into three different types. If a *Place* is created for single learner then it is called a **Solo Place**. If the Place is created for a group of learners then it is called a **Group Place** and if a teacher also accompanies the group then **Group+Teacher Place** is created. Therefore, in total we consider four different types of Places. For each type of Place a different type of **(Static Solo, Static Group, Static Group+Teacher, Dynamic)** Place-AGORA is created by the Space-AGORA.
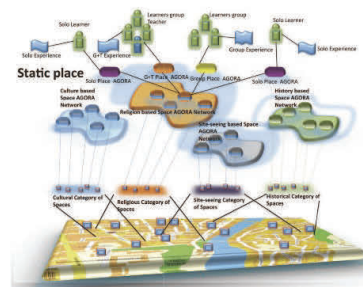

Figure 6: Three different types of static Places created over same Space

Fig 6 shows three different types of *Places* created over a same *Space*. Each *Place*-AGORA supports different functionality. A Group-*Place*-AGORA provides collaboration and communication services to the learners and maintains a higher level of trust among group members, while the Group+Teacher-*Place*-AGORA allows the teacher to restrict

or select the services that are made available to the learning group. The solo *Place*-AGORA provides the learner with the services to support solo learning activity, by helping him to visit different "learning opportunities".

a) Static Place

Static *Place* is created as learner move among different Spaces. Such *Places* are dependent on the size of learning Space for which it is created.

b) Dynamic Place

Dynamic *Places* are created based on the user goal to visit the city. The mechanism of creation of dynamic *Places* follows the following steps. 1) The user selects a goal from four different learning goals *(site-seeing, visit Religious Places, visit cultural Places, visit historical Places)* for his/her visit to the city. 2) A Special AGORA called *Space* Manager AGORA[1] performs a search in the networks of *Space*-AGORAs to find the *Spaces* which matches learner's goal. 3) The AGORAs which match the search criteria are selected and appropriate type of Static-*Place*-AGORA (based on the number of learners) are created over those *Space*-AGORAs. 4) Finally a dynamic *Place* AGORA is created on top of all the newly created Place-AGORAs. The main responsibility of this AGORA is to communicate with the *Places* underneath it. Fig 7 depicts such situation, where a solo user selects a goal to visit the city to learn the cultural aspects of the city. The size of such *Place* is not limited by the size of *Space* underneath it.
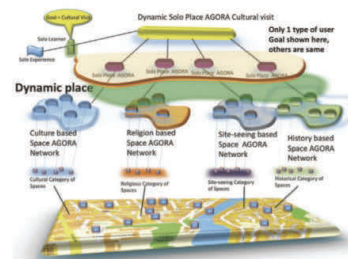

Figure 7: Dynamic Place created over many different static Places

IV. RELATED WORK

Different approaches have been used to model the learning Space for mobile learning. The main aim of these approaches is to track the position of learner in the learning space. By knowing the position of the learner it is possible to communicate with mobile device of the learner in a context aware manner. Technologies such as WLAN(802.11a,b,g),

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[1] Not discussed in this paper, interested readers should look into [5] for more details.

IrDA, RFID, GPS have been used for detecting user's position in the learning space.

Different project such as *Cyberguide* [15], *Uncle Roy all around you* [16], Can *you see me now?* [17], *Savannah* [18], *Massey Mobile Helper* [19], *Mobile and Ubiquitous Learning (MoULe) project* [20] models mobile learning environment by preprogramming the location of object in the learning environment and by detecting learner's location *(mainly though the use of GPS technology)* among those objects. While all these work pays serious attention to model spatial aspects of mobile learning environment, however they do not account for the meaning learners associate with those Spaces. This is to say that, they complete dropout the idea of Place. Many works have considered user's experience [16], [20-22], but in a mythical way. They do not provide any account for what exactly a learning experience constitutes of.

V. CONCLUSION AND BENEFITS

In this paper we have presented an approach for mapping a theoretical framework for analyzing nomadic work (mobile learning in our case) into a multi-agent framework. Our approach not only allows to make the learning system location aware, but also associate meaning to different location in the city. We consider both spatial organizations of different Spaces in the city and categorization of the Spaces according to their significance for mobile learning. Our goal was not only the consideration of conceptual solution, but also providing the details which can be adopted and implemented in a particular solution. So our solution could be treated as an attempt to bridge the gap between theory and its implementation in technology. The proposed approach was partially implemented and tested using the AGORA framework. The implementation uses Android based mobile phones for the support of mobile learners. The idea of applying multi-agent system support in the field of Mobile learning in a city allowed each entity of our system to behave in a proactive manner when supporting mobile learning activities which are distributed in the city.

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A 5. Source of Paper P7

GUMO Inspired Ontology to Support User Experience Based Citywide Mobile Learning

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Abstract— **User experience has been extensively discussed in literature, yet the idea of applying it to explain and comprehend the conceptualization of Mobile Learning (ML) is relatively new. Consequently much of the existing works are mainly theoretical and they concentrate to establish and explain the relationship between ML and experience. Little has been done to apply or adopt it into practice. In contrast to the currently existing approaches, this paper presents an ontology to support Citywide Mobile Learning (CML). The ontology presented in this paper addresses three fundamental aspects of CML, namely User Model, User Experience and Places/Spaces which exist in the city. The ontology presented here not only attempts to model and translate the theoretical concepts such as user experience and Place/Spaces for citywide context for Mobile Learning, but also apply them into practice. The discussed ontology is used in our system to support Place/Space based CML.**

Keywords- Citywide Mobile Learning; Ontology; User Model; Places & Spaces

I.   INTRODUCTION

In this paper we present an ontology that supports Citywide Mobile Learning (CML). CML is defined as *any informal learning activity that occurs through the use of handheld mobile device that is carried by the learner (i.e. user)*[1] *whose position is not fixed relative to his/her physical surroundings and people (i.e. other users) in the city* [1]. Therefore, the issues discussed here mainly reports about the different aspects of mobile learner, who engages in informal learning activities in a citywide context. The overall main goal of our work is to assist mobile learners to learn about the city, by being in the city. The work presented here is being carried out in connection to FABULA [2] project.

Central to this paper are three fundamental parts that are addressed in our ontology. The first part throws light on the **FABULA *User Model*** (FUM) that we have developed for our system to support CML. Our user model is inspired by "*General User Modeling Ontology*" (GUMO) [3], [4]. In this model we consider both static and dynamic information (i.e. knowledge) belonging to the user. The static information mainly consists of information such as demographic, contact and record of previous activities. While the dynamic

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[1] The terms user, learner and people have been interchangeably used throughout this paper.

information of the user model consists of information related to the mobility and emergent learning experience of user in the city [see section III.A]. The second part of the ontology is related to formal *representation of Chasey's notion of Place/Space* that we have adopted and applied (see [5], [6]) to structure and organize different locations in the city to support Mobile Learning (ML). The third and final important part of our ontology discussed in this paper describes how we ***explicitly represented user experience***. For this purpose we have adopted the Chasey's [7], [8] and McCarthy's [9] frameworks of user experience. The properties, attributes and classes extracted from these explanations are divided into translatable and non-translatable categories (see [5]). The attributes and properties in translatable category are mapped into ontology. Combining three different theoretical fragments into a ready to use ontology for CML is the main novelty of our work. The ontology presented here can be reused in other projects attempting to support some other form of CML. Our approach to divide city into Space and then to emulate the concept of Place over Space results in the strong analytical tool that has been successfully applied in other fields.

While reading this paper, the reader should not mix the term "*Ontology*" with "*User Model*"; user model is a part of complete ontology presented in this paper. All three sub-parts of our ontology fit together to form a coherent ontology for our system. The results highlighted in this paper are the continuation of our ongoing work [5], [6], [10]. Ontology illustrated here provides a skeleton for our complete system. The formally described form of our ontology is integrated with multi-agent framework called ***AG**ent **O**riented **R**esource **mA**nagement* (AGORA) [11] for provisioning software services to support CML.

The rest of this paper is organized as follows. Next section provides an overview of background literature. While providing the background understanding, we not only discuss the relevant literate, but also provide arguments to support our choice of using a particular approach in our work. The background studies section mainly discusses the popular user modeling approaches along with the theoretical notions of Space, Place and experience. Section III discusses three main aspects of the ontology presented in this paper. In this section we discuss FUM, ontological representation of Space/Place

and learning experiences. The later section throws light on implementation followed by conclusion and benefits.

II. BACKGROUND STUDIES

A. What is an Ontology

Ontology is a way of formally and explicitly representing knowledge dealing with some specific portion of the world. It is defined as *"a body of formally represented knowledge is based on a conceptualization: the objects, concepts, and other entities that are assumed to exist in some area of interest and the relationships that hold among them"[12]*. Commitment to a common ontology is a way for software entities to share, understand, communicate, negotiate, coordinate and reason about their actions and environments. Digging deep into the application areas of ontologies for ML is not possible in this paper. However, from the standpoint of utilizing their power for ML, several application areas can be identified, such as context awareness, composition of learning applications, recommendations, managing user preferences, managing user profiles and learning content provisioning.

B. User Profile Modeling Approaches

Several different approaches to formulate user model have been proposed and demonstrated in literature and practices. Sosnovsky and colleague [13] provide a comprehensive overview of different aspects related to user modeling. They define user model as *"knowledge source in an intelligent system which contains assumptions on different aspects of the user that may be relevant to the system's adaptive behavior. These assumptions must be separable from the rest of system's knowledge".* An important goal of different existing user modeling approaches is to define a generic user model that is useable for various application domains and can be used with no or slight modifications, extensions or adaptations. In general a generic user model can sufficiently describe various aspects of the user and when adopted by several systems, it can allow them to interoperate with each other on a semantic level. Among others the three commonly used generic user models are Friend of a Friend (FOAF) [14], Unified User Context Model UUCM[15], [16] and GUMO [3], [4].

FOAF: is targeted to support user profiles on the Web. The idea behind FOAF is to connect the scattered information about people on the Web. It allows one to formally describe the relationships that connect people, things and places. However, it focuses more on the social aspects than the user profile. Thus, it aims at collecting information about interrelations among people and has weak support to describe the detailed aspects of the user profile. FOAF uses Resource Description Framework (RDF) [17] and provides a vocabulary, which uses popular vocabularies such as basic RDF vocabulary and Dublin Core metadata elements.

UUCM: while describing user model it concentrates its efforts in describing different user contexts and premits describing several working contexts of the user. It provides an extensible set of facts that can reflect different aspects of user profile such as skills and interests etc; the same set of facts can also be used to reflect aspects of user situation and environment [16]. UUCM adopts an approach that divides the modeling complexity into two different levels of abstraction, namely abstract level and concrete level. The abstract level defines user context, user model facets, core properties for facet description, and user model dimensions. The concrete level defines an extensible set of facts which can be used to illustrate *Task, Relationship, Cognitive Pattern and Environment* dimensions of the user model.

GUMO: as a user modeling ontology it puts user at the center and attempts to articulate a very comprehensive and detailed model to formally describe the user. As the name suggests GUMO is a general-purpose (i.e. top level) user model, it is generic and can be molded to provide support in several different application areas. GUMO divides descriptions of user model dimensions into three parts: **auxiliary - predicate – range** [18]. It provides a set of basic auxiliaries to describe the user model and permits capture of different dimensions such as BasicUserDimensions, ContextDimensions, DomainDependentDimensions and SensorDimensions. Without going into the details of each dimension, these different dimensions of the user models make it possible to describe important aspects of user such as goals, interests, demographic, contact-Information, knowledge, preferences, emotional state, facial expressions, personality, psychological state, location, physical environment, social environment etc.

C. **Place** as a Meaningful Learning **Space**

The idea of separating the notion of Place from that of Space has been successfully used as an analytical tool to understand collaborative learning activities [19-21]. Based on this idea we believe that Casey's [7], [8] explanation of Place as a meaningful Space can by applied to support ML that occurs in a citywide context. In this work we only consider the *Geographical* Spaces. This is because cities mainly consist of different physical locations. Therefore, the notion of Place can be use to associate meaning to those Spaces and represent them as a meaningful location to the learners. Space as a concept relates to the physical aspect of a location and is static; Place on the other hand is a logical and conceptual concept that is attached to Space and is individually constructed for each individual (i.e. user, learner). As we shall discuss in the subsections to come, a *"Space relates to the physical world, Place is Space invested with values and meanings" [22].*

1) Space

Space is the actual landscape that exists in the physical world. In this sense Space has tangible properties and can be quantified in units. In other words it is a piece of land that has geographical coordinates and has some boundaries. I consists of the physical objects that are present within its boundreis. Physical objects which exisit in Space are the people and the interesting locations which are present inside its boundries. An

example of a Space could be a church, which consists of different physical objects such as statues, painted walls etc… and people who are present in the church.

2) Place

Place is a multi-dimensional concept. It has intangible properties and is hard to quantify. When a individual (i.e. user, learner) visits a Space, [s]he develops a personal understanding of that Space. The understood meaning of a Space when attached to it transforms it into a Place for that particular individual (i.e. user, learner). In this sense a Place is a Space with an attached understanding.

In our work, the core idea of treating Space and Place differently is based on the fact that learning activities are not isolated from the Space (i.e. location) where they occur. Therefore, Spaces where the learning occurs shall be taken into consideration when designing for CML. The exploration of these physical structures of the city commences learning activities [23]. Similar approach has been suggested by [24] as they suggest to design physical learning spaces, in other words to design buildings for ML. The perceived meaning of a Space results in the construction of a personal experience of a Place. From a learner's point of view [s]he performs learning activities in a Place consisting of other learners and like other learners his/her experience of the Place is also reflected in the properties of that Place. *"A given Place takes on the properties of its occupants, reflecting these qualities in its own construction and description, and expressing them in its occurrence as an event: places not only are, they happen"* [25].
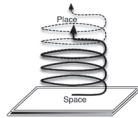

Figure 1: Relationship between Space and Place [6]

Place is a dynamic concept that occurs as an event [7] and emerges over time, two main factors that contribute to the emergent nature of Place are the evolving nature of the experiences and the movement of the learners within it. Every time a learner visits a Place which [s]he has previously visited, his/her new experience builds on the previous experiences of that Place and thus evolves. **Figure 1** depicts the relationship between Space and Place; it shows that while Space stays static the Place over it keeps evolving. Since each individual can develop a unique experience of a Place, therefore there can exist several Places over a Space.

D. Experience of Citywide Mobile Learning

According to Dierking and others [26] learning is a cumulative process consisting of a variety of learning experiences. Constructing on this argument, ML is also a kind of learning experience as suggested by Sharples and colleague [27] *"ML is the study of how the mobility of learners*

augmented by personal and public technology can contribute to the process of gaining new [….] experience". Current trends in ML's literature and many authors [28-30] are also in agreement with the view of ML as an experience.

Treating ML as experience supports our choice to use the notion of Space/Place to render the city into an area of learning. In addition to this, our goal is to support learning about the city by being in the city, from this point of view the learner's experiences of Places in the city are exactly the experiences that we want to support through our work.

Although the term learning experience is being extensively use to discuss ML, but its technical articulation is rare to be found in ML literature. Chasey [7], [8] suggested four different dimensions along which an individual can experience a Place. **Psychological Dimension:** relates to the memories, thoughts and beliefs which an individual associates to the Place. **Physical Dimension:** accounts for the influence of physical structure (i.e. Space) on the activities of an individual in a Place. **Historical Dimension:** is related to individuals' past memories of a *Place*. **Social Dimension:** highlights the role of other individuals who where present in the Place.

In order to elaborate and explain experience of a Place that occurs through the use of digital mobile device (in case of CML), it is important to also take into account the involved technological factor. McCarthy and Wright's [9], [31] propose a framework that discusses technological perspective of experience. This framework highlights different technological aspects that are missing in other theoretical elicitation (i.e. Chasey explanation of experience). Four intertwined threads and six sense making processes characterize McCarthy and Wright's framework. **Compositional Thread:** how the experience is assembled through the interplay of different subparts of the experience, which fit together to form a coherent whole. *"Refers to the narrative structure, action possibility, plausibility, consequences and explanations of actions" [9]*. **Sensual Thread:** informs about feelings perceived from the overall impression of environment. Social settings, look and feel of the environment are some of the factors influencing this thread. **Emotional Thread:** emerges from the emotional response resulting by using the technology (e.g. joy or frustration). **Spatiotemporal Thread**: is related to the affect of place and time over experience. **Six Sense making processes**: are reflexive and recursive processes by means of which people actively put together the fragments of their experience. These are *Anticipating, Connecting, Reflecting, Appropriating, and Recounting.*

III.   CITYWIDE MOBILE LEARNING ONTOLOGY

A.   User Model

As discussed earlier FUM for CML is inspired by GUMO and is the first of three central parts of our Ontology. GUMO provides a general-purpose user model that is very detailed consisting of more than 1000 concepts. However, not all the

concepts of GUMO are useable for ML. Therefore, our approach only considers the concepts which are relevant for CML. Generally speaking we have divided the FUM into two main parts. The first part deals with the static information about the user; the second part deals with the dynamic information and is related to the aspect of user mobility.
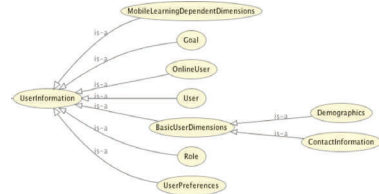

Figure 2: FABULA User Model for Supporting CML

Figure 2 shows the main concepts (i.e. classes) that we have included in FUM. MobileLearningDependentDimensions and BasicUserDimensions are the concepts that hold all the static information about user. Demographics is a concept that has properties such as *age, gender, education level, known languages*. ContactInformation has basic properties allowing to capture basic contact information such as *email, facebook ID* etc... While the MobileLearningDependentDimensions has properties such as *interests, knowledge about Places* and *ranking*. The rational behind keeping such basic information about user is to use it for the purpose of recommendations, for instance see [32].

Dynamic part of FUM consists of four main concepts, namely Goal, OnlineUser, Role and UserPreferences. The Goal concept allows the mobile learner (i.e. user) to choose his/her goal of CML. [S]He can decide to learn about *1) historical, 2) cultural, 3) religious, 4) social and 5) sightseeing* aspects of the city. By selecting the goal of CML, the control of learning resides with the learner (i.e. user) and [s]he can decide to change learning goal at anytime. OnlineUser concept has properties which allow capturing current *position, locator,* and state of *learning experience* of the learner. Availability of this information allows the system to perform location and context aware operations for the user. Role concept has properties that allow the mobile user to decide to either act as *learner* or as *teacher*. Finally the UserPreference concept has following properties, *AwarenessPreferences, PreferedLearningStyle, RecommendationsPreferences* and *VisibilityPreferences*. Through *AwarenessPreferences* a learner can increase or decrease the amount of awareness information sent to his/her mobile device by the system. Through *RecommendationsPreferences* a learner can decide to be recommended about different things such as friends, Places, and LearingActivities. A learner can decide to *learn solo*, in *group* or *group with teacher* by changing the value of

properties provided by *PreferedLearningStyle* property. Finally a learner can also decide if [s]he wants to visible to other mobile learners in the city.

B. Ontological Representation of Place/Space

The next main part of our ontology is the formal representations of theoretical concepts of Space and Place. As discussed earlier in theoretical terms Space is a static concept that is mainly related to the physical aspects of a location. **Figure 3** depicts the conceptualization we have adopted to model Space. We consider that a city can consist of several Spaces; a Space has certain boundaries defined by the four different coordinate points. There may be several *Learning Opportunities* present inside the boundaries of the Space. For instance a monument or a statue is a *Learning Opportunities*. These *Learning Opportunities* also have associated geographical boundaries and different possible *Learning Tasks* associated to them. When a learner performs *Learning Tasks* [s]he learns something new about the city, which [s]he was not aware before. The theoretical explanation of Space discusses it purely as a static concept, however our conceptualization of Space extended the theoretically static concept of Space by representing it through two different types of attributes, namely static and dynamic. As shown in Figure 3, static attributes represent the physical aspect of the Space. While the Dynamic attributes are related to the movement of the learner, as the learners enter and leave a Space the number of learners present in the Space keep changing dynamically.
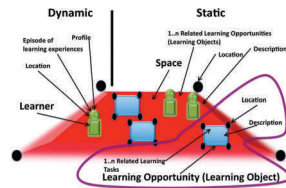

Figure 3: Structure of Space[5]

Place is a logical structure which is constructed from the combination of previous Learning Experiences (see II.D) of individual learner. In the theoretical explanation neither Space nor Place has any size limit. Therefore, theoretically these concepts are elastic and can be stretched or shrunk as needed. However, this is not possible in practice and cannot be implemented. To overcome this limitation of theory we propose two different types of Places. The first type of Place is *Static Place* and the second type is the *Dynamic Place*. *Static Place* is constructed over single Space and thus is constrained by the geographical boundaries of the underlying Space. Dynamic Place can be constructed dynamically over several Spaces. It reflects the properties all the underlying Spaces; these ideas are discussed at greater length in [5].

Figure 4 depicts the concepts representing Space and Place

in our ontology. Location is the super concept representing Space. LearningCity, LearningSpace and LearningOpportunity are different types of PhyicalLocation. Each kind of Space has properties that allow associating cultural, historical, religious, social, and sightseeing description along with ranking. These descriptions and rankings are used by the system when constructing a Dynamic Place for the learner. Other properties of Spaces allow learners to attach tags and leave comments about Space.
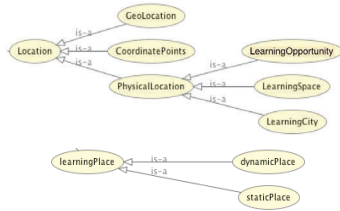

Figure 4: Ontological Concepts of Space/Place

Also shown in the Figure 4 are two different kind of Places which can be constructed over Space: StaticPlace and DynamicPlace. Parameter that characterizes the type of Place to be either dynamic or static is the learner's learning Goal [see section III.A]. A learner can decide to learn about all the Spaces in the city, or [s]he can decide to learn about a particular aspect of the city (e.g. culture, social, religious, historical, sightseeing). In case a learner decides to learn about a particular aspect of the city, the system then chooses particular Spaces within the city which matches the learning Goal of the learner. A dynamic Place is then constructed for the learner over chosen Spaces.

C. Ontological Representation of Learning Experience

The last and final important part of our ontology deals with the representation of CML experience. We consider that every time a learner visits a Space an episode of learning experience is created. This consideration is based on the metaphor of Place as an event as described by Chasey. Furthermore, as discussed during section II.D, we use two different theoretical frameworks that can be use to understand experience. Therefore, we adopt an approach that takes into account the intersection of both frameworks. This is because both theoretical frameworks to explain the concept of experience are complementary and considering both is important as argued previously in section II.D.

The translatable aspects identified by intersecting the two theoretical frameworks are as follows [see [5] for details].
1) *Social Experience*: mainly relates to all the other learners who are present in the Space
2) *Historical Experience:* is the collection of all the previous learning epesiode of a learner

3) *Psychological Experience:* over all design impression that a learners gets by using our mobile learning application. This includes how the user ranked the mobile application, and number of learning tasks which were performed correctly by the learner
4) *Physical Experience:* Consists of the attributes such as time, Place where and when the expreince occurred.
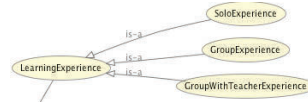

Figure 5: Ontological Representation of Learning Experience

All the translatable aspects are integrated as properties of three different kind of learning experiences as shown in **Figure 5**. SoloExperience occurs when the learner's preferred style of learning is Solo, the GroupExperience occurs when the learning happens in a group, and the GroupWithTeacherExperience occurs when the group of learner is supported by the teacher. Apart from the translation of theoretical concepts to form CML experience. We also add into experience the trace of learner's movement in the city along with the learning tasks that user perform at different locations (i.e. positions) in the city. Based on this information the Place created for the learner adapts for the subsequent visit.

IV. IMPLEMENTATION

For the implementation of our ontology we use Web Ontology Language (OWL) [33]. The completely ontology is tightly integrated with "Java Agent Development Environment" (JADE) and it is used with our multi-agent framework called AGORA. Other parts of this ontology are agent actions and predicates, which are not discussed here. Our multi-agent architecture makes full use of the concept and properties presented in this ontology, which allows interoperation of agent actions within our system and between our system and mobile application developed for CML. Software agents of FABULA system use it for communication, coordination and negotiation.

V. CONCLUSION AND BENEFITS

In this paper we have presented an ontology that can be used by any system aiming to support CML. Our ontology unifies three important aspects that are of fundamental importance for any CML support system. Ontological representation of Spaces and Places ensures that the location where learning activities occur are given due consideration. Furthermore, it highlights different types of Places that can exist in citywide context. Finally, the mythical notion of learning experience is translated using two well-established theoretical frameworks. By virtue of this ontology a designer can take a more unifying look at all the important aspects of CML. Since our ontology is independently developed from implementation issues. Therefore, adopting this ontology or

it's extended version in other system is possible with very little of no effort, thus allowing reusability. Our work is different from previous works, which mainly focus only on the theoretical aspect with very little consideration of their true application in terms of technology. The presented user model FUM is use in FABULA project and it allows capturing statics and dynamic aspects of a mobile learner in a citywide context. The different learning experiences of the learners are use to create Places for them, when they visit Space they have previously visited their previous experience in that Space influence the creation of Place for them, the Place then ensures that they perform only those Learning-Tasks that they have not performed previously (see [1] for details). Since our role in FABULA is mainly technical, therefore evaluation of this work with real user and field data are not performed.

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Appendix B: Secondary Papers

B 1. Information About P2

Khan, A.Basit., and Matskin, M., (A. B. Khan & Matskin, 2009). **FABULA Platform for Active e-Learning in Mobile Networks**. Sánchez, I. A., Isaías, P., editors. Proceedings of the IADIS International Conference Mobile Learning (2009), Barcelona, Spain. Pages 33-41. ISBN 9789728924775. IADIS Press.

Abstract: Connectedness has become a common term of today's world. The ever-increasing availability of network access has opened new possibilities for individuals to collaborate and share information with one another. With the communication infrastructure in place software support can be used to describe, publish and discover the learning resources. An individual carrying a mobile device has the opportunity to get access to a dynamic and collaborative environment full of similar individuals. In such an environment there is a huge potential to learn form others through sharing of experiences and conducting shared tasks. Learning methodologies can take significant advantage of the capabilities of information technologies and can take the learning experience a step further. However there is still a great need of e-learning systems, such a systems can make use of communication infrastructure. This paper is written within the scope of project FABULA. By the virtue of this paper we present the work done to construct a service based e-learning architecture for FABULA system. This architecture uses Web-services and software agents to support efficient collaboration and cooperation for learning activities.

Relevance to this thesis: this paper presented our first step to design a framework to support mobile learning (FFC-ML). It looked at different e-learning frameworks and presented our framework, which considered software-agents(i.e. AGORA) as a core building block. The framework we presented in this paper laid the foundation for our work.

B 2. Information About P5

Khan, A.Basit., and Matskin, M., Rossitto, C., (A. B. Khan et al., 2011). **Towards a Places and Spaces based city-wide mobile learning through multi-agent support**. Hussain, F., K., Chang, E., editors. Proceedings of the 5th IEEE International Conference on Digital Ecosystems and Technologies Daejeon, Korea. Pages 164-169. ISBN 978-1-4577-0872-5. IEEE Press.

Abstract: *This paper illustrates how the conceptualization of Places can be used to inform the technical design of mobile learning system. We apply the concept of Place in a multi-agent framework for supporting informal city-wide mobile learning activities. By taking input from the theoretical framework for analysing collaborative learning activities, we adopt the structure and organization of multi-gent framework. The functionality and components of the system are defined in light of the theoretical work. This work bridges the gap between theory and it's application in technology for mobile learning in our project.*

Relevance to this thesis: *this paper presents the initial ideas to map notion of Place into AGORA multi-agent system. Work presented in this paper combines the theoretical perspective with the implementation. This paper also contributes towards the development of the ontology to support CML.*

Appendix C: Co-authorship Agreements for Published Papers

C 1. Agreement for P1
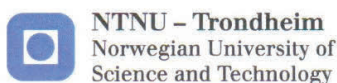
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Co-authorship regarded publication included in "Basit Ahmed Khan's" PhD thesis titled "Applying Multi-Agent Software System to Support Citywide Mobile Learning "
(cf. the PhD regulations § 7.4, section 4 and the dr.philos regulations § 3, section 5, http://www.ntnu.edu/ime/research/phd/forms).

Candidate's described contribution to:

Khan, A.Basit., and Matskin, M., (2010). A Platform for Actively Supporting e-Learning in Mobile Networks. Parsons, D., editor. International Journal of Mobile and Blended Learning (IJMBL 2010). Issue 1. Volume 2. Pages 55-79. ISSN 1941-8647. IGI Global.

Basit's Contribution: *under the competent guidance of* Prof. Mihhail Matskin, *I "Basit Ahmed Khan" is the first author of this paper*

Statement by the co-author:
I hereby confirm that the doctoral candidate's contribution to this paper is correctly identified above, and I consent to "Basit Ahmed Khan's" including it in his PhD thesis titled "Applying Multi-Agent Software System to Support Citywide Mobile Learning "

Stockholm, 05.09.2011

Prof. Mihhail Matskin (Main Supervisor)

C 2. Agreement for P2
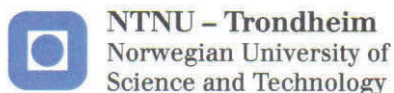
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Khan, A.Basit., and Matskin, M., (2009). FABULA Platform for Active e-Learning in Mobile Networks. Sánchez, I. A., Isaías, P., editors. Proceedings of the IADIS International Conference Mobile Learning (2009), Barcelona, Spain. Pages 33-41. ISBN 9789728924775. IADIS Press.

Basit's Contribution: *under the competent guidance of* Prof. Mihhail Matskin, *I "Basit Ahmed Khan" is the first author of this paper*

Statement by the co-author:
I hereby confirm that the doctoral candidate's contribution to this paper is correctly identified above, and I consent to "Basit Ahmed Khan's" including it in his PhD thesis titled "Applying Multi-Agent Software System to Support Citywide Mobile Learning "

Stockholm, 05.09.2011

Prof. Mihhail Matskin (Main Supervisor)

C 3. Agreement for P3

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Candidate's described contribution to:

Khan, A.Basit. and Matskin, M,. (2010). AGORA Framework for Service Discovery and Resource Allocation. Bellot, G. O., Hideyasu, S., Ehmann, M., Dini, C., editors. The Fifth International Conference on Internet and Web Applications and Services ICIW(2010), Barcelona, Spain. Pages 438-444. ISBN 978-0-7695-4022-1. IEEE Computer Society Press.

Basit's Contribution: *under the competent guidance of* Prof. Mihhail Matskin, *I "Basit Ahmed Khan" is the first author of this paper*
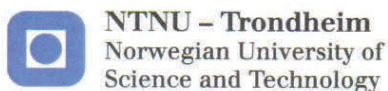
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C 4. Agreement for P4
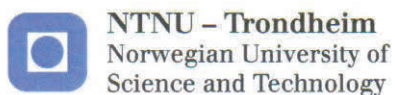
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Candidate's described contribution to:

Khan, A.Basit., and Matskin, M., (2010). Towards an Engineering of Multi-Agent Eco-Systems. Hussain, F., K., Chang, E., editors. Conference Proceedings of 4th IEEE International Conference on Digital Ecosystems and Technologies (2010) Dubai, United Arab Emirates. Pages 340-345. ISBN 978-1-4244-5553-9. IEEE Press.

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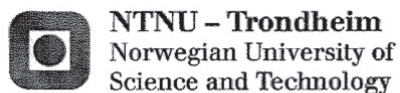
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C 5. Agreement for P5

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Candidate's described contribution to:

Khan, A.Basit., and Matskin, M., Rossitto, C., (2011). Towards a Places and Spaces based city-wide mobile learning through multi-agent support. Hussain, F., K., Chang, E., editors. Proceedings of the 5th IEEE International Conference on Digital Ecosystems and Technologies Daejeon, Korea. Pages 164-169. ISBN 978-1-4577-0872-5. IEEE Press.

Basit's Contribution: *under the competent guidance of my main supervisor, and expert advices of "Chiara Rossitto", I "Basit Ahmed Khan" is the first author of this paper*

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Stockholm, 05.09.2011

Prof. Mihhail Matskin (Main Supervisor)

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To the evaluation committee

Co-authorship regarded publication included in "Basit Ahmed Khan's" PhD thesis titled "Applying Multi-Agent Software System to Support Citywide Mobile Learning "

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*Statement by the co-author:*
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Stockholm, 05.09.2011

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Prof. Mihhail Matskin (Main Supervisor)

Stockholm, 05.09.2011

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Chiara Rossitto

C 6. Agreement for P6
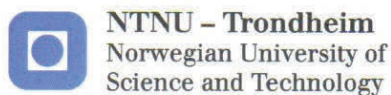
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Basit's Contribution: *under the competent guidance of* Prof. Mihhail Matskin, *I "Basit Ahmed Khan" is the first author of this paper*

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C 7. Agreement for P7
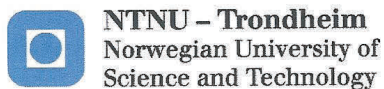
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Khan, A.Basit., and Matskin, M., (2011). GUMO Inspired Ontology to Support User Experience Based Citywide Mobile Learning. Proceedings of 2nd International Conference in User Science and Engineering (i-USEr), Malaysia. IEEE Press

Basit's Contribution: *under the competent guidance of* Prof. Mihhail Matskin, *I "Basit Ahmed Khan" is the first author of this paper*

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IEEE Press.

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