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A Mashup Based Framework for Multi Level Healthcare Interoperability

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A Mashup Based Framework for Multi Level Healthcare Interoperability

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Abstract

During the past few years, various healthcare models and e-Health 2.0 technologies have been developed in order to effectively deliver the right information to the right process to provide effective and efficient healthcare services. On the other hand, healthcare delivery is evolving from disease-centered to patient-centered where patients are active participants in their healthcare delivery. Thus communications and collaboration among different healthcare actors is taking place on a much larger scale. There is also an increasing demand for personalized health systems facilitating the effective management of information, simplifying communication and collaboration, and supporting applications and services for meeting different users' specific requirements and ongoing needs. In order to properly address the aforementioned challenges, a framework is needed to advance information integration and interoperability of health applications and services in a controlled manner.

In this thesis, we present a framework which allows patients and other healthcare actors to collaboratively develop personalized online health applications according to their specific and ongoing needs and requirements. For this purpose, we illustrate how Web 2.0 collaborative technologies, such as mashups, can represent an adequate foundation for implementing such framework. The value and capabilities of mashups in healthcare have already been studied and demonstrated, and this technology is able to

provide an interoperable framework for communication and integration between healthcare processes and applications. We believe that integration and interoperability of health applications/services can be defined at the following levels: Process Level, System Level, and Data Level. The interoperability and integration of services at the system and data levels have already been intensively researched. However, not enough consideration has been given to interoperability issues at the process level. Healthcare must have interoperable systems and interoperable people who will use the systems. Therefore, a shift from a technology-driven implementation to a process-driven conceptual model is needed.

Our aim in this thesis is to further research how Web 2.0 technologies and tools, such a mashups, can facilitate the exchange of processes between various healthcare entities and actors, and the role of mashup patterns for enhancing the interoperability and integration of healthcare services and applications.

This thesis is dedicated to my beloved parents **Shirzad** and **Zahra** for instilling the importance of hard work and higher education;

and also to my dear sister **Shohreh** and my brother-in-law **Mehrdad** for their unique encouragement and support.

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Publications

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Nomenclature

Acronym	**Definition**
API	Application Programming Interface
B2B	Business-to-Business
B2C	Business-to-Customer
B2G	Business-to-Government
C2C	Customer-to-Customer
CPOE	Computer Physician Order Entry
DSS	Decision Support System
EBM	Evidence-Based Medicine
EMR	Electronic Medical Record
HIS	Health Information System
HL7	Health Level Seven
HTML	Hyper Text Markup Language
IT	Information Technology
ICT	Information and Communication Technology
openEHR	Open Electronic Health Records
OHIP	Ontario Health Insurance Plan
PHP	Hypertext Preprocessor
PHR	Personal Health Record
RSS	Really Simple Syndication
SCM	Supply Chain Management
SNOMED-CT	Systematized Nomenclature of Medicine-Clinical Terms
SOA	Service-Oriented Architecture
xPHR	Extended Personal Health Record
XML	eXtensible Markup Language

Chapter 1: Introduction

1.1 Problem Statement

The 2001 Institute of Medicine (IOM) study "Crossing the Quality Chasm: A New Healthcare System for the 21st Century" described how our healthcare system fails to provide consistent, high quality care to all people who need it (Institute of Medicine 2001). In particular the study pointed out that the healthcare system is poorly organized to meet the challenges it faces while healthcare delivery is changing from care provided by a single provider and setting to care provided by multiple providers (e.g. primary care providers and specialists, psychologists, physical therapists, etc.) across multiple settings (e.g. hospitals, physician offices, etc.). Therefore, it is critical that healthcare delivery is coordinated effectively, and transitions across multiple care settings are actively managed; otherwise, patients are likely to be frustrated, medical errors are more likely to occur, and avoidable utilization of healthcare services will increase (Shih et al. 2008). Two of the key recommendations from the IOM study are the development and delivery of care by high performing patient-centered teams in order to coordinate care across different diseases, sites and services over time, and the use of information technology (IT) to enhance healthcare delivery. In other words, two main changes need to be made to our healthcare system from the IOM model which are increased use of IT and reengineered care processes that cut across diseases and locations. However, those recommendations are a challenge to implement as healthcare is still largely built around individual tasks and information usage, which is clearly inappropriate for the level of integration the healthcare system needs to provide coordinated care across distributed settings. On one hand, healthcare is one of the most knowledge-intensive sectors where different models and technologies are being developed in order to effectively deliver information across the healthcare process with the aim of providing better services and treatment to patients. On the other hand, healthcare delivery is evolving from disease-centered to patient-centered where patients are active participants in their healthcare process, and the patient's participation and expertise are greatly encouraged and valued. Furthermore, current healthcare policies advocate greater involvement of patients in self-care (Timpka et al. 2008) due to the fact that optimal outcomes of healthcare interventions are achieved when patients become active participants in the healthcare process (Bos et al. 2008). However the challenge is effectively managing the growing number of information and services. The amount and availability of health information is increasing and the number of health applications and services available on the web is growing rapidly. In addition, people's use of the web as a primary source of health information has increased dramatically (Karkalis & Koutsouris 2006). The implication of that growth in information and web usage is that information integration and collaboration on a large scale has become considerably complicated. Overall there is an increasing demand for personalized health systems facilitating the effective management of information, simplifying communication and collaboration, and supporting miscellaneous applications and services for meeting different users' specific requirements and ongoing needs. However, there is a lack of frameworks and methodologies in order to properly address the aforementioned challenges, and also to advance information integration and interoperability of health applications through recent technologies, such Web 2.0 technologies, in a controlled manner.

1.2 Thesis Motivation and Contributions

Integration and interoperability of healthcare applications are still an issue for many healthcare organizations due to the fact that, in the current developments of patient-centered healthcare models, information integration is a critical point, and proactive delivery of the right information to the right person at the right time, usually as part of the healthcare delivery process, is extremely important for making more soundly based decisions, leading to better patient outcomes and fewer mistakes (Benson 2009). Therefore, there is a high demand for developing a framework to advance healthcare interoperability in order to efficiently, and affordably, exchange healthcare information and enhance interoperation of services among healthcare applications in a *controlled manner* where the patients are in charge of their own care and their participation throughout the treatment process are highly encouraged. It is important to mention that in such a framework, a systematic structure for capturing the broad perspectives on health service delivery (Timpka et al. 2008) and supporting multi-disciplinary decision-making should be considered where the services are customizable, adaptable to multiple settings and module-based (re-useable, re-purposable and re-connectable).

The contribution of this thesis is a *mashup-based framework for multi-level healthcare interoperability*. The framework serves as a model for how mashup technology can facilitate multiple interoperability requirements between various healthcare applications, entities and actors; and how this technology can be used for implementing a web-based patient-centric healthcare environment. In addition to the framework, we propose a *system design process* and a *healthcare value web analysis* in order to clearly demonstrate how all the actors of the healthcare process are able to work on the development of a healthcare environment collaboratively and in a structured manner. In addition, relevant mashup patterns are presented consequently in order to show how they are able to play an important role for enhancing the interoperability and integration of healthcare services and applications, especially at the process level.

In summary, this research attempts to answer the following questions:

- What are the healthcare interoperability requirements for collaborative care delivery?
- Can a multi-level mashup-based framework be developed to meet these requirements?
- How can mashup patterns be used for implementing these interoperability requirements?

1.3 Thesis Methodology and Organization

Design science research was the overarching methodology we used in our research. According to Hevner et al. (2004), design science research addresses research through the building and evaluation of artefacts designed to meet the identified business needs, where purposeful artefacts are built to address heretofore unsolved problems and they are evaluated with respect to the utility provided in solving those problems. In other words, design science research uses a cyclical model of designing, building, and evaluation of outcomes in order to develop constructs, models, or methods (Hevner et al. 2004). Outcomes from design science research can involve developing new research questions or developing a model or framework which can be evaluated against the research objectives. We developed a framework and used it to implement proof-of-concept applications (i.e., implementations) to illustrate a set of interoperability requirements derived from a collaborative care case study (Section 4.1). In particular, the following steps have been taken throughout our research:

1. Review the literature in order to identify potential issues and problems.
2. Analyse the identified problems and examine the literature to realize the possible approaches for solving the problem.
3. Identify the strengths and shortcomings of the recognized approaches.
4. Develop a mashup based framework for multi level healthcare interoperability towards adapting a patient-centered environment.

5. Analyse a collaborative care case study and derive a set of healthcare interoperability requirements from it.
6. Examine how the proposed framework is able to address the identified healthcare interoperability requirements.
7. Validate the proposed framework through implementing proof-of-concept applications to illustrate how it can address the interoperability requirements derived from the collaborative care case study.
8. Discuss the proposed framework, draw conclusions and identify potential future work.

This thesis is organized as follows:

In Chapter 2 we define the underlying concepts for the issues we address in this thesis by providing background information on interoperability within and outside healthcare, accompanied by a description of the technologies which are potentially able to support interoperability at different levels.

In Chapter 3 we first shortly describe our research method and then we present and discuss our proposed mashup based framework for supporting healthcare interoperability at different levels.

In Chapter 4 we introduce a case study of collaborative healthcare delivery and present multiple healthcare interoperability requirements.

In Chapter 5 we prove the concept of our proposed framework through illustrating multiple implemented healthcare scenarios in a mashup environment, the IBM Mashup Center.

Finally, in Chapter 6 we summarize our contributions, provide concluding remarks, and discuss possible future extensions to this thesis.

Chapter 2: Literature Review

As mentioned in previous section, healthcare delivery is evolving from disease-centered to patient-centered where patients are becoming active participants in their healthcare delivery and treatment process. This means that more communication and collaboration among all healthcare actors are needed now than ever before with the main aim of enabling them to share and exchange health information and work on possible treatments collaboratively. In fact, successful communication is not only an information transaction process between communicators but is one that builds a common understanding of the exchanged information (Weigand & Dignum 1997).

Along with the demand for improving communication among healthcare actors, there is also an increasing demand for personalized healthcare systems that facilitate effective information management, simplify communication and collaboration, and support applications to meet user requirements. For patients, the main aim of personalized healthcare is tailoring the right treatment, for the right person, at the right time. And for healthcaregivers, personalized healthcare provides the opportunity to improve the quality of care through more precise treatments and diagnoses, and also for having an access to more accurate and most updated patients' data. Implementing such personalized healthcare environments where communication and collaboration among healthcare actors are well-facilitated is very challenging, and in order to overcome such challenges, there is a need to advance the integration and interoperability of healthcare applications in a controlled matter. Integration of healthcare applications is about rendering disparate pieces of healthcare information, functionalities and applications useable for care purposes. And interoperability of healthcare applications is defined as the ability of two or more healthcare systems or components to exchange information and to use the information that has been exchanged. In fact, well-integrated and interoperable healthcare systems are the enabler of successful communication and collaboration among healthcare actors.

In this chapter, first an overview of the concepts which will be discussed in this thesis will be given, and then we will go into details by defining what communication in healthcare means and why is it required for the necessary coordination and integration in any healthcare environment, followed by discussing how Information and Communication Technology (ICT) is being adapted to healthcare industry for enhancing communication and integration issues. Afterwards, a background on interoperability will be provided where we will discuss the concept of interoperability at three different levels both outside healthcare and also in the context in healthcare. Finally, we will discuss the Web 2.0 technologies which are being widely used in healthcare in order to examine how these technologies are able to support integration and interoperability of healthcare applications at different levels.

2.1 Overview of Concepts

The concepts which will be discussed in this thesis together with their definitions are summarized in the following table:

Table 1. Overview of Thesis Concepts

Concepts	Definition
Collaborative Healthcare	Type of healthcare delivery which requires a high level of interactions, communications and collaboration among healthcare actors
Collaborative Technologies	Those technologies which are intended for improving the social interactions among users letting them to communicate and share information more effectively.
Health 2.0	The Web 2.0 technologies which are applied to healthcare.
Healthcare Actor	Individuals or organisations that affect or are affected by healthcare systems and applications.
Healthcare Integration	Rendering disparate pieces of healthcare information, functionalities and applications useable for care purposes.
Healthcare Interoperability	The ability of two or more healthcare entities such as healthcare systems, healthcare actors, etc. to successfully communicate with each other and exchange data and information; this will be achieved by integrating healthcare data, systems and processes.
Personalized Healthcare	Tailoring the right treatment for the right patient at the right time to improve the quality of care and to provide precise treatment and diagnoses to patients.

2.2 Healthcare Communication

Communication is critical to the healthcare industry due to the fact that communication and collaboration among different entities of healthcare process is a major part of information flow in health care, and effective communication throughout the healthcare process plays a crucial role in providing adequate healthcare services to patients. However, communication failures and inadequate exchange of information between healthcare actors may lead to the occurrence of medical errors and relevant issues such as adverse drug events (Bates et al. 2003). In this context, Information and Communication Technologies (ICT) are able to improve communication in healthcare by increased sharing of health information among authorized healthcare actors and by providing them with electronic access to healthcare records which may lead to elevating the standard of care for everyone and engaging the healthcare actors in opportunities for improving patients' health and well-being. There are generally two possible approaches to adapt the Information Technology into Healthcare:

1. **Top-Down Approach:** In this approach, hospitals and/or healthcare providers are the actual creators of health care services and platforms, and the patients are provided with pre-defined functionalities and services, and they have minimal influence throughout the design process.
2. **Bottom-Up Approach:** In this approach, patients and partially healthcare providers are the creators of health care services and platforms. For this purpose, patients are actively involved throughout the design process of health

platforms (Health 2.0-based environments) and they are provided with a set of tools and materials in order to tailor the health applications (through Health 2.0 technologies) according to their specific needs and requirements.

Since healthcare delivery models are evolving towards patient-centered ones, the second approach is appeared to be more demanding and promising in compare to the first approach; however, the second approach requires an underlying infrastructure that can support interoperability of healthcare systems, healthcare data and healthcare processes. In addition and in parallel with the aforementioned approaches, there are four major scenarios in adapting information technology into *healthcare communication* (Pirnejad et al. 2008):

- **1st Scenario:** In this scenario, information technology play the role of *data repository* where it is used to store and retrieve patient data for different purposes;
- **2nd Scenario:** In this scenario, information technology serves as a *communication medium* where certain healthcare interactions are made asynchronously. Technologies which are mainly used for data communication in healthcare such as Internet, e-mail and Electronic Data Interchange (EDI) fall into this scenario.
- **3rd Scenario:** In this scenario, information technology acts as the integrator to put different pieces of patient data together in an asynchronous manner, where the main aim is to help care providers to acquire metadata. Central EMR

(Electronic Medical Records) accessible at multiple locations in a hospital fall into this scenario since it is able to reduce the number of communication processes, such as phone calls or call pages, for accessing patient information produced by various health caregivers.

- **4th Scenario:** In this scenario, information technology takes over the role of *human communicators* and participates in a synchronous interaction with humans. In such a scenario, information technology is able to interpret information followed by generating appropriate feedback or reactions. Decision Support Systems (DSS) fall into this scenario as they are able to provide health caregivers with necessary advice without interrupting their work or their colleagues. Such systems act as *acknowledged professionals* and have access to different health information sources.

It is being argued that successful communication and information sharing in healthcare is defined as leading to interoperability of healthcare systems, but the move toward healthcare systems which are interoperable at different levels is a major challenge due to the fact that current healthcare systems are not designed for such a movement (Weber et al. 2009). Therefore, during the design of healthcare systems and proposing healthcare solutions, we need to realize whether the aforesaid scenarios and approaches are being applied, and whether the future healthcare system will be able to deliver the expected requirements.

2.3 Collaborative Healthcare Delivery

This type of healthcare delivery requires a high level of interactions, communications and collaboration among healthcare actors, especially between healthcare professionals and patients. Usually, collaborative healthcare delivery is consisted of interdisciplinary teams where frequent and in-depth collaboration and interactions between team members together with collaborative planning and activities are required in order to manage the complexity of clinical practice (Patel et al. 2000). Interdisciplinary teams involve more complex patient cases and are instances when the knowledge and expertise of healthcare providers from one profession are integrated together, in a collaborative manner, to set common goals for care (Kuziemsky et al. 2010). An example of an interdisciplinary team could be a patient with cancer who is being transitioned to palliative care. In such a healthcare setting, a task completed by one team members will have implications for the other team members and decisions are often made in a collaborative manner. Therefore, the interdisciplinary teams would require a Health Information System (HIS) to support collaborative tasks such as group decision making, brainstorming about a problem, and automated notifications to all team members of changes in the patient data.

In general, any HIS designed for collaborative teams need to support the process of different healthcare providers and team types as well as supporting decision making and education. In addition, any HIS intended for supporting collaborative healthcare teams should allow flexibility in the design due to the fact that the roles and responsibilities of healthcare providers can be dynamic and change over the period of the treatment process.

2.4 Interoperability outside Healthcare

According to Interoperability Working Group, "interoperability is a property of a product or system, whose interfaces are completely understood, to work with other products or systems, present or future, without any restricted access or implementation" (AFUL 2010). However, the concept of interoperability is very complex and there are varieties of definitions for interoperability due to the fact that interoperability is a very context-specific concept. Therefore, rather than trying to define a single and generic definition for interoperability, it is very important to carefully consider the context for the discussion. In the context of healthcare, interoperability is the means of integration of data and processes to support collaboration and other healthcare activities. In fact, interoperability is the essential factor in building the infrastructure to create, store, exchange and manage health-related information. According to US Federal Health Information Technology Strategic Plan, in order to advance high-quality, safe and efficient health care, information must be effectively exchanged among diverse participants, and for this purpose "health information, health IT systems and products must use consistent, specific data and technical standards" (U.S. Department of Health and Human Services 2008); this is where the healthcare interoperability benefits lie. In fact, when there is a high level of interoperability among healthcare systems, secure and instant access is being provided to various actors of healthcare process and right information is therefore being delivered to them at the right time and at the right place; by this, they are able to make a better informed decision which may certainly lead to better treatment to patients.

Benson refers to three interoperability levels (Benson 2009):

- **Technical interoperability** moves data across two computer systems without understanding the exchanged data; in this thesis, we call this type of interoperability *data interoperability.*
- **Semantic interoperability** ensures the two computer systems have a common understanding of the exchanged data; in this thesis, we call this type of interoperability *system interoperability.*
- **Process interoperability** coordinates work processes across different people so they can work together; also called *process interoperability* in this thesis.

Since interoperability is a complex entity, in order to better set the context of interoperability in healthcare we draw upon interoperability experiences in supply chain management (SCM). SCM represents the set of processes that integrate suppliers, manufacturers, distributors and retailers as a virtual organization in order to deliver products to a customer. SCM relies on process and information interoperability across the entire supply chain process, both internal and external to an organization. SCM uses the terms "digitization" or "digital enablement" to describe the replacement and integration of processes using ICT such as the Internet (Lee 2000). A key feature of digitized SCM is the shift from connecting physical processes to information-based integration (Zhu et al. 2004). As digitized SCM systems evolved, some believed there was a disconnect between the theory and practice of digitization in that expensive ICT solutions were being implemented without understanding the implementation needs and relevant factors needed in practice (Van Donk 2008). Supply chains were able to succeed at interoperability by focusing on the processes of SCM. Tailoring interoperability to support those processes has allowed SCM to evolve. In designing ICTs to integrate supply chains it has been recognized that attention must be paid to specific processes, such as how human decision makers interact and exchange information since those have been shown to impact the information channels and ICT design used in a supply chain (Van Donk 2008).

2.5 Healthcare Interoperability

Healthcare is similar to SCM in that it is moving towards the design of digitally enabled systems that will replace physical processes and provide the means for processes to be conducted across disparate settings (Raghupathi & Kesh 2009). Healthcare is also struggling with the implementation of ICT systems as numerous healthcare ICT projects end up as failures (Avison & Young 2007). The main reason for these failures is that healthcare delivery, particularly via distributed collaborative teams, is challenging. While industries such as banking and manufacturing have succeeded in developing interoperable systems, it has been pointed out that healthcare is unique in its need to facilitate highly integrated yet personalized care via multidisciplinary teams located in differing settings (Avison & Young 2007).

Although the unique features of healthcare preclude the direct transfer of interoperability research from other domains, we do suggest that there are some key lessons that are transferable. The primary lesson is the need to understand interoperability at the processes level. A key message from business interoperability with financial, manufacturing and supply chain systems was the need for processes to be the driver of interoperability. To date, much of the research on healthcare interoperability has been focused on technical interoperability and to a lesser extent semantic interoperability. This research has led to the development of interoperable systems using technologies such as Extensible Markup Language (XML), Web Services and Service-Oriented Architectures (SOA) (Sartipi & Yarmand 2008) and interoperable systems using terminology standards such as HL7 (specific standards created by the Health Level Seven organization), SNOMED-CT (Systematized Nomenclature of Medicine-Clinical Terms), and reference model based architectures such as the openEHR (an open standard specification in health informatics that describes the management and storage, retrieval and exchange of health data in Electronic Health Records) archetypes (Garde et al. 2007). However, a key shortcoming in existing healthcare interoperability research is that it has not, for the most part, focused on the underlying processes of healthcare delivery. The fact is that healthcare interoperability needs to consider more than just data; this means that although the ability of health systems to exchange and interpret healthcare data is important, but we must also consider interoperability among actors and healthcare processes. For example, complex healthcare delivery, particularly collaborative team based care delivery, requires interoperability of data as well as the processes that act upon the data. Complex healthcare delivery includes facilitating collaboration, the dissemination and use of evidence, and the social aspects of communication. Therefore, healthcare process interoperability ensures we have both interoperable computer systems and interoperable actors and processes using the healthcare systems. In addition, understanding and supporting the processes could be argued as the key to developing true interoperable healthcare systems. Shortliffe and Blois stated that the key to understanding the automation of medical records such as through the electronic health record (EHR) is making sense of the underlying processes that use the EHR (Edward Shortliffe & Blois 2000). They further suggest that we should not look at healthcare ICT as an object or product but rather as a set of processes. In addition, (Campbell et al. 2006) and (Ash et al. 2007) similarly showed that the key to understanding computer physician order entry (CPOE) systems was to understand the underling work processes and interactions of people who used the CPOE systems. Therefore we need to look at ways of understanding process interoperability and designing systems to support it. For these reasons, the focus of this thesis is mainly on healthcare interoperability at the process level for better filling the current gaps in literature and also identifying potential future researches.

2.6 Technologies for Supporting Process Interoperability

Despite the focus on interoperable systems and data we need to remember that healthcare delivery is based on processes. The different actors in healthcare delivery conduct processes as part of care delivery and it is processes that generate and use data.

The aforementioned IOM healthcare system objectives of effective, efficient, safe, collaborative patient centered care (Chapter 1) are all macro level processes and thus the true test of interoperability will be how well it helps us implement those objectives. Therefore understanding and supporting process interoperability could be argued as the key to developing true interoperable healthcare systems. We also must keep in mind that healthcare systems are socio-technical systems (Coiera 2004) involving the interaction of people, policies, processes and technologies. In that context we need to design and evaluate ICT systems from the perspective of all levels of interoperability such as people, processes and technologies.

2.6.1 Collaborative Technologies

Increased collaboration is one of the primary goals for healthcare system reform. Therefore we need increased focus on the design of technologies to support collaboration. Obviously, the Web is changing the way people and businesses communicate and do business, and is gaining popular acceptance faster than any other communication medium. In this context, Web 2.0, the second generation of services available on the Internet which is also called *collaborationware*, harnesses the Web in a more collaborative and interactive manner where its main emphasis is on improving the social interactions among the Web users and let them communicate and share information online more effectively. Tim O'Reilly defines Web 2.0 as follows:

"Web 2.0 is the *Web as platform*, spanning all connected devices; Web 2.0 applications are those that make the most of the intrinsic advantages of that platform:

delivering software as a continually-updated service that gets better the more people use it, consuming and remixing data from multiple sources, including individual users, while providing their own data and services in a form that allows remixing by others, creating network effects through an *architecture of participation*, and going beyond the page metaphor of Web 1.0 to deliver rich user experience" (O'Reilly 2005).

Web 2.0 technologies, such as blogs, wikis, RSS feeds, social networks, mashups, etc. have been increasingly adopted by many businesses and industries with the main aim of offering their services online and considering the Web users, as customers, as the main part of their business process (O'Reilly 2006). Web 2.0 technologies, designated as Health 2.0 when applied to healthcare, are also being widely developed in the healthcare sector due to their simplicity, accessibility, ease-of-use, and rapidity of deployment (Kamel Boulos & Wheeler 2007). Over the past few years, there has been a significant rise in the use of Health 2.0 for health and health care purposes, and these technologies have been increasingly adopted by many caregivers and health providers towards creating a patient-centered environment where both caregivers and patients are able to directly communicate with each other and work on possible treatments collaboratively, share and exchange health information, provide emotional support and awareness for improving the quality of treatment, patients' health and well-being. Through Health 2.0 technologies, patients are able to become active participants, consumers and producers of health information.

Health 2.0 technologies can support collaborative care delivery because they allow collaboration across multiple providers and settings; and they have the potential to improve healthcare delivery by providing improved access to information and support for healthcare interventions and team based care delivery (Juzwishin 2009)(Senathirajah & Bakken 2009). However the use of Health 2.0 is still in the early stages. Research is needed to understand the specific processes, information and services needed by the different actors as part of collaboration and how all of those can be integrated by technologies such as Health 2.0. Some of the most popular Health 2.0 technologies being widely used in healthcare are discussed as follows:

Blog: Blog or Weblog is a two-way content management tool where people are able to enter their thoughts, ideas, suggestions, and comments (Murugesan 2007). Blog entries, also known as blog posts, are made in journal or diary style and they are normally presented in chronological order with the latest entry listed first (most recent first). A blog post might contain texts, images, videos, or links to other blogs and websites; however the majority of blogs are textual. Blog posts are consisted of a title, body, permanent link (also called *permalink*), post date, category (or tag), comments, trackback (it is a function to notify another blog that the user added a post to his/her blog which is related to a post/comment on its blog; trackback is considered as a powerful mechanism for communication between blogs), and pingback (it is a function to request notification when somebody links to one of user's posts). In general, a blog can be private (internal to an organization/enterprise), or public (open to anyone). Blogs are easy to create through free services like Google Blogger (http://www.blogger.com) and Web users are able to easily contribute to blog posts by leaving their comments, tag the posts, etc. In the context of Healthcare, blog entries could include information on prescriptions of medication, daily comments about health incidents, and even measurements and examination results (Karkalis & Koutsouris 2006). There are currently many medical/health related blogs available online such as "the Cancer Blog" (Weblogs, Inc. 2010) and "Clinical Cases and Images" (Dimov 2010), where many patients and health professionals provide information on different health topics, and share their experiences and emotions.

Wiki: A Wiki is a simple collaborative-authoring system for creating and editing content. It can also be considered as an expandable collection of interlinked web pages. A wiki allows any user to quickly and easily add, remove, or edit content (McLean et al. 2007). Users may also track changes made to an article (wiki page) in order to be able to examine the accuracy and quality of the changes. Supporting multiple users, built-in search engine, simple site structure and navigation, simple templating, and asynchronous contribution are the main features of wikis. Similar to blogs, wikis can be used as a source of information and knowledge where medical and health related dialogue and information can be shared among all the actors of the healthcare process or specific project groups; therefore they can virtually collaborate with each other and be part of a virtual community of practice. There are many successful medical wikis nowadays such as Flu Wiki, Wiki Surgery, etc.

Really Simple Syndication: RSS, also called Rich Site Summary, is a set of XML-based web-content distribution protocols used by blogs, wikis, and news sites to announce recent additions of content or updates to a website. In other words, RSS informs users about updates to blogs or Websites they are interested in. RSS allows users to subscribe to a web page or a blog, through an RSS aggregator, and receive notification when the page is updated. RSS can be considered as syndication plumbing which allows flow of content between websites and applications on the web (Kamel Boulos & Wheeler 2007). RSS can have a strong impact on achieving information integration on e-health through facilitating data aggregation from disparate sources. For example, where doctors need to be informed on new data about their patients, RSS feeds are able to notify them about new available data. In addition, personalized feeds could be generated by intelligent software algorithms to inform patients or healthcare professionals on new evidences, articles or advices which are relevant to the patients' condition through correlating information from patients' electronic health records (Karkalis & Koutsouris 2006).

Social Networks: Social networks are online group-forming applications which are intended for connecting people through shared information interests. They allow users to build personal profiles, find old and new friends, locate links with people through mutual friends or acquaintances, etc. Social networks are relatively new kinds of virtual communities that define and build on member relationships by means of their being part of that community (Barsky & Purdon 2006). A health social network is a website where users, especially patients, are able to find heath information at different levels ranging from a basic tier of emotional support and information sharing to consulting with healthcaregivers. One of the key values of health social networks is the potential to find other patients in similar health situations and share information about conditions, symptoms and treatments (Swan 2009). According to PatientsLikeMe, "patients who choose to explicitly share health data within a community may benefit from the process, helping patients engage in dialogues that may inform disease self-management (Frost & Massagli 2008).

Mashups: Mashups are Web pages or Websites which are able to dynamically reuse the existing data sources or Web applications from heterogeneous sources and combine them into a single integrated application. As discussed in (Koschmider et al. 2009), the idea behind the term mashup is not new and in fact the integration of disparate resources has always been an issue during the software development process where some data and functionalities are provided by external systems, and mechanisms are presented in order to specify them properly. However, mashups are gaining momentum mainly because on one hand, as described in (Jhingran 2006) and in (Abiteboul et al. 2008), the number of applications on the Web is growing very fast, and therefore there is a need to combine them in order to meet users' specific requirements. And on the other hand (Koschmider et al. 2009), through mashups even non-technical people are able to create new content and represent resources without much effort or knowledge of programming languages through enhanced user interfaces, and therefore the main emphasis of mashups is on user-driven, simple and fast integration development and specifications. In fact, mashups are generally created using APIs, and simple and well-documented APIs make mashup development easier (Murugesan 2007). According to Ogrinz, APIs are the most stable integration point because of the fact that they reflect a site/organization's commitment to expose data and functionality (Ogrinz 2009). In addition, as mashups pull and integrate data and services dynamically from different sources, they can grow and evolve over time. In fact, as argued in (Cheung, Kashyap et al. 2008), optimal value will be gained when mashups can be created across the resources. Also, since all mashups inherently take advantage of interoperability, each user is able to convert his or her mashup from using one data source or service to another, and as a result users' needs are better satisfied in a timely manner.

Generally, there are two types of mashups which are defined by their capabilities, functionalities and target group: consumer mashups and enterprise mashups. Consumer mashups are usually associated with Web 2.0. These types of mashups require a lesser amount of programming knowledge due to the fact that they rely on public Websites that expose well-defined APIs and data feeds. Examples of consumer mashups are iGoogle, Dapper, Intel Mash Maker, etc. Enterprise mashups are more complex and are normally aimed for enterprises and organizations, and they can be interpreted as an evolution of SOA (Watt 2007). These types of mashups are created by IT experts and are being used to rapidly deliver products where ordinary users are not directly involved during the development process but they benefit from IT's ability to provide solutions more quickly.

The main aim of enterprise mashups is to facilitate the process of service composition within an enterprise or an organization (Zahoor et al. 2009). Examples of enterprise mashups are Yahoo! Pipes, Serena Mashup Suite, etc.

Mashups can be developed through mashup patterns, which are the best practices for enabling us to see how others have accomplished specific tasks together with understanding how technologies, especially Web 2.0 technologies, can be leveraged to create situational mashup solutions (Brown 2008). Mashup patterns are organized into five main categories: Harvest, Enhance, Assemble, Manage, and Testing (Ogrinz 2009). Each category together with its core activities are described below:

1. *Harvest patterns* are a class of solutions based on obtaining data from sources previously viewed as not potential or outside the reach of current systems or tools.
2. *Enhance patterns* are aimed for extending and improving current systems, generally without the assistance of the original developers.
3. *Assemble patterns* show how new solutions can be provided by combining data and presentation from multiple sources.
4. *Manage patterns* help leverage existing assets more effectively, especially when the idea is not to build new solutions but rather to manage the ones we already have.

5. *Testing patterns* can be used to perform basic testing functions or requirements, such as user acceptance testing, before deploying a final solution.

Despite the fact that the number of mashups is increasing rapidly, there are only few applications of mashups in healthcare. As an example, Ohad Greenshpan et al. proposed a mashup-based patient-centric xPHR (Extended Personal Health Records) system in order to assess the potential of latent effectiveness in the mashup approach (Greenshpan et al. 2009). Their system includes components of three main classes namely Medical, Personal, and Collaboration and it is part of a larger system that provides personalized monitoring of patients with notification on anomalies to relatives and caregivers.

2.7 Mashups in Healthcare

Integrating the processes, information and actors that are involved in healthcare delivery requires a framework to support interoperability in a controlled manner. Among Web 2.0 technologies described above, mashups can be a potential solution due to the fact that mashups are considered a fast-growing integration approach in the field of data management because of the flexibility and creativity involved in their development as well as the functionality they offer to users (Gasser & Palfrey 2007). In addition, mashups aim to integrate not only data and services, but also real-time complex web-based applications. As mentioned, the capabilities of mashups in the healthcare domain have been demonstrated by Ohad Greenshpan et al. who proposed a mashup-based patient-centric Extended Personal Health Record system (xPHR). They also suggested that mashups are an ideal technology for the collaborative requirements of Health 2.0 since they provide a great potential to improve the quality of care through empowering patients by delivering patient-centered and easy-to-use solutions. We strongly support their suggestion and we believe that mashups will help all healthcare actors to customize their applications based on their ongoing needs and situational problems. As a result, information is adapted easily into exactly the form that actors need, and subsequently healthcare providers and organizations are possibly able to reduce development time and cost and can lower the cost of customizing information for individuals. However, to date there are limited applications of mashups in healthcare and those that exist are mostly designed for integration and interoperability at the data level, such as those presented in (Cho 2007) where mashups has been used for aggregating different data sources to provide a comprehensive view of global state of infections diseases and their effects on human and animal health through. Such an application, HEALTHmap, may be valuable for healthcare professional and librarians who want to stay tuned with information on global health news.

On the other hand, as Jin Yu et al. argued in (Yu et al. 2008), comprehensive frameworks are lacking in mashup development to speed the overall process and to enable inexperienced end-users to mash up their own Web applications. Some mashup frameworks do exist such as those discussed in (Yu, Benatallah, Saint-Paul et al. 2007) and (Yu, Benatallah, Casati et al. 2007), however we are not aware of any generic mashup-based framework specifically developed for the healthcare environment for supporting interoperability at multiple levels including people, data and processes. Such a framework would encourage healthcare actors to collaborate with each other effectively, would enable healthcare applications to communicate with each other through standard technologies and open protocols, and it would also bridge the gap between healthcare providers and patients aiming for providing a patient-centered environment.

2.8 Current Research Knowledge and Gaps

In addition to what we have discussed earlier in this chapter, the literature is demanding to research on the following areas:

- Evaluating the use of Web 2.0 in clinical practice and medical education with the aim of establishing best practice models: Careful thinking, testing and evaluating are the most demanding requirements in this area of research in order to leverage the emerging Web 2.0 technologies to improve the medical teaching and learning productivity (McLean et al. 2007).
- Investigating potential models of interaction and information interchange, identity management and authorization schemes in the context of Web 2.0: Interconnecting and interrelating the health information from various sources which are relevant to one patient with the aim of creating a personal virtual health environment containing links to all the health information a person, especially a patient, owns or is interested in (Karkalis & Koutsouris 2006).
- Developing a systematic framework for capturing health information (especially the grey information) from different Health 2.0 applications in a meaningfully

filtered manner to be presented to the patients, clinicians, and health professionals: Adequately involve stakeholders and prospective users' representatives (students, patients, health care professionals, etc.) in any research and development process for better realizing the goals of patient-centered care (Boulos et al. 2006).

- Evaluating an implemented Health 2.0 system based on its architecture, and if possible in different practical settings: Level of user participation in developing and managing health content should be considered during the evaluation; and according to Health Care Standards, this participation should be structured and the medical quality of the services provided should be assured (Timpka et al. 2008).
- In the context of health and health care services and education, there is a need to raise awareness of Web 2.0 tools and the possibilities they offer, and an urgent need to conduct quality research to inform better use of Web 2.0 applications. In other words, patients must be empowered to build their needs into any technology on offer (Kamel Boulos & Wheeler 2007).

The topics that we have discussed so far together with the current research knowledge and gaps in the literature are all summarized in the following table:

Table 2. Current Research Knowledge and Gaps

Topics	Current Knowledge	Current Gaps
Healthcare Systems	Focused on Individual Settings	Lack of Understanding of Applying Healthcare Services in Distributed Settings
Collaborative Healthcare Delivery	Available Tools; Targeting Specific Healthcare Actor	Lack of Understanding of Applying Flexible Tools; Targeting All the Healthcare Actors in a Controlled Manner
Healthcare Interoperability	Well-defined at Technical Level, Less-defined at Semantic Level	Poorly Defined at Process Level
Health 2.0 Applications	Believed to Support Collaborative Care Delivery	Need for Flexible Frameworks; Formal Evaluation
Mashup Technology in Healthcare	Applications for Specific Purposes mainly at Data Level	Comprehensive Multi-level Frameworks

Chapter 3: Research Method

Design-oriented research was used as the methodology in our research in the form of a "search process to discover an effective solution to a problem" (Hevner et al. 2004). In our research, we followed the three main stages of design research approach consisting of: (1) Identifying the problem area and its relevance from a case study and previous research, (2) developing the framework as a design artefact; and (3) validating the application of the framework through a relevant scenario (Bell et al. 2006). Identifying the problems was conducted through a literature review in order to identify the gaps in collaborative healthcare delivery and healthcare interoperability, together with analyzing a collaborative case study which was based on interprofessional collaborative care (ICC) delivery. The case study was based on interviews and field observations for collecting data. We analyzed the data using content analysis, a method suited for analyzing text data. Data analysis using content analysis is focused on the characteristics of the data with particular attention to the content or contextual meaning of the text (Hsieh & Shannon 2005). The purpose of the content analysis was to analyze the data in order to identify interoperability requirements which are discussed in Chapter 4. In fact, content analysis allowed us to make sense of the complexity of collaborative care delivery and the interoperability requirements that are needed to support it, and this approach helped us to further understand the technical and behavioural (i.e., process, collaborative, social) aspects of interoperability.

We then followed an iterative approach in developing a new mashup-based framework – which will be discussed in this chapter – in order to address the gaps identified in the previous stage and achieve the interoperability requirements described in our case study in Chapter 4.

Once the framework was developed completely, it was validated as a prototype against the case study through multiple proof-of-concept implementations in a mashup-based environment in order to show how mashup technology, and its patterns, could support the identified interoperability requirements (Chapter 5).

3.1 Conceptual Models and Frameworks

As mentioned in chapter 2, a generic mashup-based framework specifically developed for supporting healthcare interoperability at multiple levels is lacking in literature. In fact, Chapter 2 describes various interoperability applications and challenges of collaborative care delivery, and our proposed framework uses those applications to overcome the challenges in collaborative care delivery. In order to devise such a framework we need to first identify the main entities of a healthcare process and define the value that each entity is able to provide throughout the development process. We call this course of action *Healthcare Value Web Analysis*, and the following section provides more details about it. In fact, Healthcare Value Web Analysis is part of our purposed framework and it can be considered as the preliminary step in developing the framework. This analysis can be modified according to any healthcare settings and it provides us with an opportunity to structure the participation of healthcare actors aiming for filling one of the gaps in literature discussed in Chapter 2.

3.1.1 Healthcare Value Web Analysis

Healthcare processes consist of various actors working together with the goal of improving patients' health condition and well-being. In order to develop a healthcare system, the first step is to identify the actors of the healthcare process and define their relative importance as well as the value which they are able to provide throughout the delivery of healthcare services. As suggested by Boulos et al., it is essential to adequately involve stakeholders and prospective users' representatives (patients, health care professionals, healthcare students, etc.) in any research and development process for better realizing the goals of patient-centered care (Boulos et al. 2006). For this purpose, we adapted the Value Web Analysis (Kornak et al. 2004) as a modeling technique for capturing, visualizing, and then analyzing the network of interactions to define the value of each participant to the network. In order to better perform the Value Web Analysis in healthcare, we first shortly describe the Value Web framework experiences in SCM, and then we will focus on creating and analyzing a Value Web for the patient-centered healthcare.

Traditionally, major industries were controlling the value chain all the way from sourcing and production to distribution and end-user (customer) support; therefore their supply chain structure was vertically integrated. However, realizing the inefficiencies inherent in such a structure, industries started to adopt horizontally integrated structures gradually. Actually, the Value Web framework is a fundamental departure from the traditional value chain concept, be it vertical or horizontal, where it considers an industry and its constituents to be presented by analogy of a network rather than a linear sequence. This framework describes a customer-focused and organization-coordinated network that establishes strategic relationships required to provide the customer with an offering consisted of all services, products, and information that fulfill a customer's needs and requirements. Such an interconnected framework is intended to response to customer demand where the customer is located at the core of the web with every business decision, being made by other constituents, evaluated against its impact on customer value.

The reason that such a framework can also be applied to healthcare is, as previously mentioned, that healthcare models are evolving towards patient-centered ones where the patient plays a role of customer and it has become the focal point of attention in healthcare services, while other healthcare actors are focused on delivering value to the patient. Delivering such a value takes the form an exchange meaning that where a healthcare environment provides something of value to a patient, there is usually a financial payment in return. It is important to mention that exchanges of values also take place among other healthcare actors as web participants; those exchanges, for example between a healthcare provider and the government, can be either financial or informational. As a result, exchange processes illustrate the relationships and interdependencies among healthcare actors within a healthcare environment where the main aim is to understand the opportunities for satisfying unmet patient demands.

In Value Web Analysis, the value of each participant (the actor of healthcare process) is generally defined based on three dimensions (Kornak et al. 2004): Informational Value (I), Intangible Value (T) and Economic Value (E). Informational value includes the level of information and exchange of content that each actor of healthcare process provides or receives; intangible value includes the level of influence, opinion and support or similar unquantifiable values among the actors; and economic value describes the exchange of services or products, usually involving financial transactions.

Figure 1 shows the possible actors of the healthcare process together with the potential interactions among them.

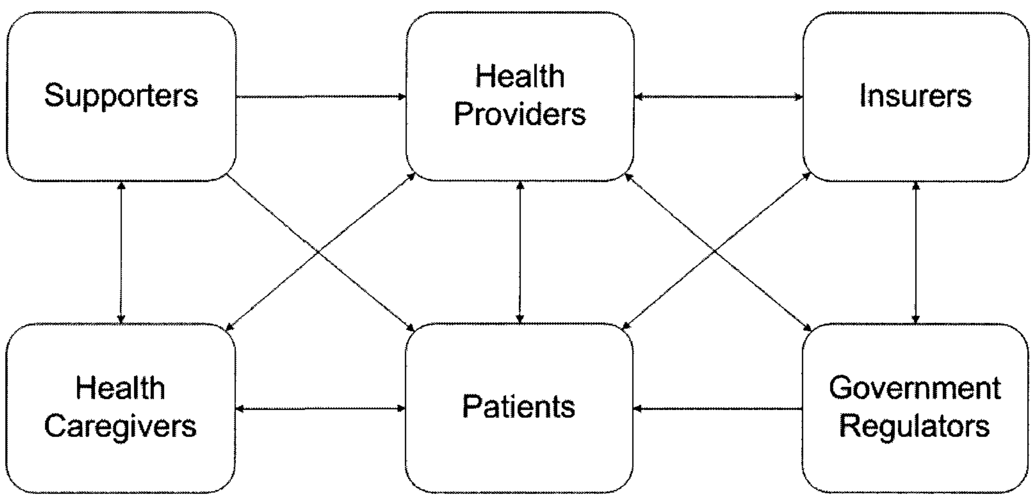

Figure 1. Healthcare Actors and Interactions

The interactions between the actors of the healthcare process can be indicated in terms of tangible interactions and non-financial relationships. Non-financial relationships are mainly influential, meaning that they may influence actors' decisions. The arrows indicate the directions of information flow among the actors of healthcare process.

Now that the possible actors of the healthcare process and the value dimensions are specified, the next step is to create a generic value matrix in order to show how two actors possibly interact with each other in terms of informational, intangible, and economic values. Table 1 shows the generic value matrix of a healthcare environment.

Table 3. Generic Value Matrix for the Healthcare Environment

		Outbound: Value Delivered to Others					
		Patients	Health caregivers	Health Providers	Supporters	Government Regulators	Insurers
Inbound: Value Delivered from Others	Patients		I, T, E	I, T, E	I, T	-	I, E
	Health caregivers	I		I, E	I	I	-
	Health Providers	I, E	I, E		I	I, T	I, E
	Supporters	I	I	I		-	-
	Government Regulators	-	I, E	I	-		I
	Insurers	I	-	I	-	I	

I = Information; T = Intangible; and E = Economic

As shown in Table 1, almost all the actors of the healthcare process interact with patients during the treatment process: health providers provide informational and economic (health service) values to patients; healthcaregivers provide informational and intangible values to patients; supporters (including family, friends, peers, etc.) provide informational (e.g., patient's background, habits, reactions, etc.) and intangible (e.g., opinions, support, etc.) values to patients and may influence the treatment process as they usually have some affiliation with the patient; insurers provide informational and economic (insurance plan) values to patients; and government regulators may provide informational (changes in regulations) and economic (e.g., OHIP, financial support, etc.) values to patients. It is important to mention that patients may also provide different values to the other actors at various stages of the treatment process and therefore values are being provided from both sides. On the other hand, values are not being only provided to/from patients; although each actor of the healthcare process may provide values to various actors during the treatment process with the aim of ensuring optimal results for the patients and therefore improving patients' health conditions. As indicated in the above table, both healthcaregivers and health providers provide a maximum level of values to patients, and therefore they can be considered as the *key actors* of the healthcare process. In addition, supporters and insurers are the next actors in the process who provide an average level of values to patients. We believe that actors who provide an average and above average level of values to patients should be involved during the development of any patient-centered environment. On the other hand, since patients are not the only users of a healthcare environment, the same idea should be considered during the development process. This means that, for example, while specific applications or services are being developed for health providers, actors who provide average and above average level of values (like patients, healthcaregivers, government regulators and insurers) should be involved during the development process in order to provide inputs and opinions for facilitating better interactions among them. As a result, in any development of a patient-centered environment, the values of each actor should be evaluated, and based on their level of values they should be involved at different stages of the development process; this is how participation at different phases of the development process can be defined in a controlled manner. The above analysis may differ in different health settings or countries, and it can be modified accordingly.

3.1.2 Mashup-Based Framework for Multi Level Interoperability

Now that the main actors of healthcare process are defined based on the values that they are able to provide throughout the development process, our mashup-based framework for multi level interoperability will be presented in this section. The framework can be considered as an architectural map for supporting the health interoperability at different levels. We refer to the framework as a multi level interoperability framework due to the fact that there are three main interoperability levels defined as data, processes, and systems.

As discussed in Chapter 2.5.1, the ability of Mashups to reconcile multiple data sources or applications as well as their ability to evolve over time makes them an ideal basis for an interoperability framework. Mashup technology provides a foundation for enhancing interoperability among healthcare actors, processes and applications due to the fact that mashups have openness, data reuse and interoperability at their core (Anderson 2007). Each user is able to convert his or her mashup from using one data source or service to another, and as a result, users' needs are better satisfied in a timely manner (Gasser & Palfrey 2007).

Our multi level interoperability framework is made up of two main parts, the framework itself, and the mashup patterns that facilitate interoperability, at the following levels, within the framework:

- **Process Level:** Coordinating work processes across different people so they can communicate, collaborate and work together. Therefore, this level of interoperability is mainly about collaboration among healthcare actors and it can be called *collaborative interoperability* as well.
- **Data Level:** Moving and exchanging data across healthcare applications and systems. This level of interoperability is mainly for ensuring that healthcare data is being exchanged successfully.
- **System Level:** Ensuring that healthcare systems are interoperating with each other and they are well-integrated. This level of interoperability is mainly about integrating diverse healthcare systems.

Each part of our multi level interoperability framework is discussed below.

Mashup-based Interoperability Framework

Our framework provides an environment for healthcare actors to directly communicate and collaborate with each other and personalize their healthcare environment according to their own needs, while healthcare applications are able to work together (interoperate) and exchange health information in a way that the information is effectively managed by all the actors of the healthcare process.

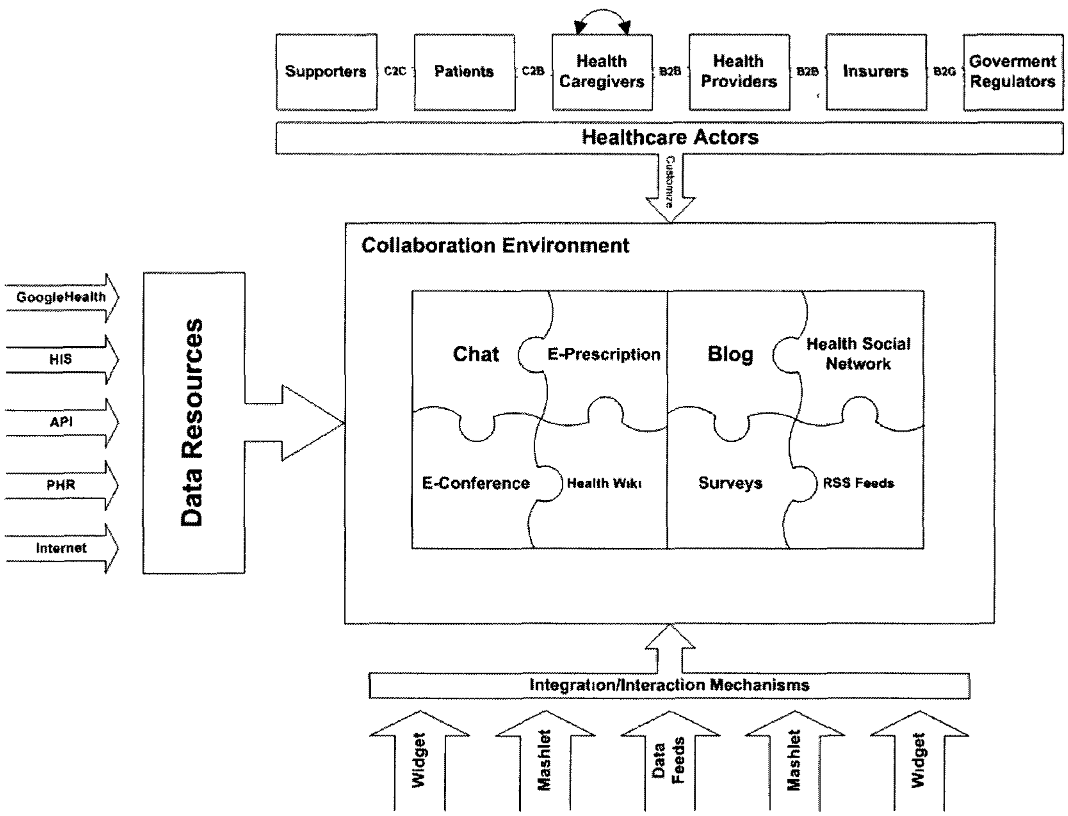

Figure 2. Mashup-based Interoperability Framework

The Mashup-based Interoperability Framework (see Figure 2) consists of four main components: healthcare actors, collaboration environment, integration/interaction mechanisms and data resources. Each component is discussed below.

Healthcare Actors: This part of the framework considers all the actors which are (or might be) required throughout the process of healthcare delivery. The main actors are identified through our Healthcare Value Web Analysis described previously in this chapter, and the relationships among them are defined based on e-business relationships as specified in (Trites et al. 2005). Our framework uses patients and their supporters (e.g., family members) instead of customers (C); health caregivers, health providers and insurers instead of businesses (B); and government regulators instead of government (G). Through mashup technologies, all the actors of the process are provided with a set of Web 2.0 tools and technologies throughout the design and development processes enabling them to customize and tailor the web-based collaboration environment according to their specific and ongoing needs, while being able to directly communicate and collaborate with each other.

Collaboration Environment: The center of the framework is the actual environment where different Health 2.0 tools and applications such as blog, health social network, health wiki, etc. are offered to healthcare actors in a way that they can utilize and customize them according to their needs and preferences. Each of these tools can be used for improving collaboration among the healthcare actors with the aim of achieving interoperability at the process level.

Integration/Interaction Mechanisms: At the bottom of the framework, integration or interaction mechanisms are located where users are able to drag and drop widgets onto the mashup environment and configure them interactively. Widgets represent application domain functions or information specific functions intended for user-specific needs which can be easily placed into a web page. Widgets are called by different names such as widgets, mashlets, gadgets, etc. Widgets can be written in any programming languages

(Java, PHP, etc.) and can be as simple as an HTML (HyperText Markup Language) fragment. Widgets can have their own graphical user interface or be presented as web Services. Examples of widgets are a "To Do List" widget, an "Image Viewer" widget, a "Medical Data Analyzer" widget, or even an Electronic Health Record (EHR) widget. Through similar widgets patients can be enabled to have access to their medical records, and providers are able to have access to patients' medical history at the point of care with the aim of delivering effective and efficient care.

Data Resources: This part of the framework is used for interoperability at the data level where we considered all the possible data sources to be used throughout the healthcare process. On the left side of the framework, data sources are in place as suppliers of the mashup environment, which may include content and application functionality as well. This means that in order to gain the maximum possible value from our framework, we need to consider all the health resources including different health information systems (e.g., pharmacy systems) and Internet-based Applications such as Personal Health Record (PHR) systems. It is worth mentioning that the resources can be sourced via the well-defined public interface, named Application Programming Interfaces (APIs). An API is an interface provided by an application that lets users to interact with/respond to data or service requests from another applications or Websites. In other words, APIs facilitate data exchange between applications which may lead to creation of new applications. In fact, mashups are generally created using APIs, and simple and well-documented APIs make mashup development easier (Murugesan 2007). According to

Ogrinz, APIs are the most stable integration point because of the fact that they reflect a site/organization's commitment to expose data and functionality (Ogrinz 2009). There are also risks in using companies' APIs in terms of their continued support, reliability and security; therefore, businesses (especially healthcare providers) should choose dependable and reliable API services from legitimate providers.

Mashup Patterns

We augment our interoperability framework with a set of mashup patterns, which represent the tools to achieve the interoperability at different levels. Generally, mashup patterns can be considered as roadmaps of how companies can and have utilized mashup technology to address challenges already considered dismissed or expensive to solve; refusing to address such challenges would add to the tangle of unmet expectations. Through mashup patterns, we are able to see how others have accomplished specific tasks together with understanding how technologies, especially Web 2.0 technologies, can be leveraged to create situational mashup solutions (Brown 2008). In other words, a mashup pattern does not solve a problem in itself, but rather it is a general form that helps us think about the structure of the solution. While many IT departments try to reuse their available physical assets such as code and libraries, and mashup patterns complement these efforts by providing a format for converting good ideas into repeatable architecture designs.

The applications of the mashup patterns, described in Chapter 2, in the context of the healthcare interoperability vary in each healthcare setting and case. In fact, the key to success with mashup patterns is to realize which one will fit perfectly within an environment for addressing a problem. Therefore, for each healthcare setting or case study, the most suitable mashup pattern(s) should be first identified in order to better meet the interoperability at the required levels. Further information regarding these patterns together with few applications of them will be provided in the next two chapters.

Chapter 4: Case Study

In order to validate and refine our proposed mashup-based interoperability framework, we applied it to a case study of collaborative healthcare delivery provided by (Kuziemsky & Varpio 2010). In fact, collaborative healthcare delivery provides a rich perspective of interoperability because it involves care delivery by multiple providers across multiple settings. And as a design science research, our aim was to first present our mashup-based framework and then apply it to such a case study in order to better validate the framework and examine its capabilities.

4.1 Case Study Description

In the provided collaborative case study (Kuziemsky & Varpio 2010), an interprofessional collaborative care delivery was studied over a six month period (February – July 2008) at an urban, 9 bed in-patient teaching hospice, where the collaborative care teams were consisted of nurses, physicians, medical residents and fellows, coordinating administrative staff, personal support workers, volunteers, patients and patient family members. According to the case study, 91 members of the hospice's healthcare team participated in their study. The hospice team generally worked asynchronously, where team members have minimal fact to face interactions. Each patient had a family physician that would coordinate the patient's care. However the family physician's office was external to the hospice and as a result the physician was not at the hospice very frequently. While a nursing staff member was always present on the ward, other members of the healthcare team, including physicians, were intermittently present. Data exchange and communication was a mixture of electronic and paper based tools. Communication between the staff on the ward and the external providers was mainly asynchronous.

Family physicians managed their patient cases remotely and through periodic visits to the hospice. However because family physicians are not palliative care specialists they would sometimes require assistance with complex cases from a palliative care specialist. That assistance could be provided through consultation with a palliative care specialist or through access to medical evidence.

Aside from the inpatient ward there is also a day hospice program where patients would stay in their own home but spend the day at the hospice engaging in various clinical and social activities. Patients enjoyed the social interaction of the day hospice but due to scheduling, resource and other logistical issues; they were often only able to attend the day hospice one or two days a week.

As the case study was based on interviews and field observations for collecting data, we analyzed the data using content analysis which focuses on the characteristics of the data especially on the contextual meaning of the text. As a result of such an analysis, we indentified the interoperability requirements which are discussed in this chapter.

4.1.1 Data Sources Study

The data sources of the case study were based on non-participant field observations and participant interviews at the hospice in order to understand collaborative care delivery and its interoperability needs. For the field observations, a trained qualitative research assistant collected field notes through 90 hours of non-participant observations. The observational data included a wide range of routine day-to-day collaborative care processes and tasks, including interprofessional team activities (such as team rounds, patient admissions and discharges, and managerial meetings) and individual activities that had collaborative care implications (such as patient charting and other data entry activities, medication order creation, and communication exchange activities). Observations were conducted at different times of the day and on different days of the week in order to maximize the breadth of collaborative care activities included in the data. And regarding participant interviews, 30 semi-structured interviews were conducted with healthcare team members including 8 nurses, 6 physicians, 6 medical residents, 3 team coordinators (e.g., nursing coordinator), 2 personal support workers and 5 volunteers. Interviews ranged between 30-90 minutes in length. All interviews were transcribed by a research assistant who rendered the data anonymous.

4.2 Interoperability Requirements

The data analysis revealed several examples of where interoperability was needed; this is where content analysis was used to make sense of the complexity of collaborative care delivery and the interoperability needs that are needed to support it, which helped us to further understand the technical and behavioural aspects of interoperability. We formally represent those examples as *interoperability requirements*. In total, we identified six unique interoperability requirements: data, team task, policy and procedure, collaborative, social, and knowledge exchange.

4.2.1 Data Interoperability

Patient centered care means that care delivery is tailored to each individual patient and therefore all collaborative team members need to have data about the patient's current status and detailed treatment plan(s). A large amount of collaborative activities, such as rounds meetings or shift change, were spent discussing and updating patient status and treatment plans. However palliative patient cases are complex and thus patient status and treatment plans have many dimensions including physical, psychosocial, and spiritual. All of those data sources needed to be integrated and customized to support the different needs of the different providers.

4.2.2 Team Task Interoperability

Collaboration to support a patient case is not static but rather a healthcare team comes together depending on the specific needs of the patient and the capabilities of the healthcare providers. Thus teams need to be assembled based on patient needs but also the abilities and skill set of the providers to deliver the patient needs.

Different team iteration will require different information and process supports. Therefore data needs to be tailored to specific team processes such as care planning or treatment provision.

4.2.3 Policy and Procedure Interoperability

Clinical processes are governed by policies and procedures at different care centres. Those policies can influence treatment and communication processes as well as other clinical decisions. In other words, policies and procedures can impact what can and cannot be done in HIS and how tasks need to be done. In fact one physician from the case study emphasized the importance of policies and procedures by stating that in collaborative care delivery, 30% of the work is about technology and 70% of it is about policies & procedures.

Admission criteria to a unit and medication entry are two processes where policies and procedures are important. The case study took place in a hospice and one of the policies was that patients could not be admitted if they were undergoing acute interventions such as chemotherapy or radiation. Another hospice policy was that medications requiring intravenous administration were not allowed, which impacted medication options. Thus any technology we design must incorporate these policies and procedures with their applicable processes.

4.2.4 Collaboration Interoperability

A common source of tension in the case study was that decisions were made without consulting the other care team members. This largely occurred because of the asynchronous nature of how care delivery was provided. Family physicians rarely attended rounds meetings because of scheduling issues. However rounds meetings are where patient decisions are often deliberated and made. Team members need a common place to see what decisions need to be made so they can contribute to the collective decision making process as described by a physician. In addition, part of collaboration interoperability is the ability to brainstorm ideas. Team members are often asynchronous but they still need to pass ideas off each other in order to ensure that the benefit of working in a team is realized.

4.2.5 Social Interoperability

Social interactivity is a large part of healthcare delivery. Studies have shown that the ability of patients to discuss their illness socially can have positive implications on outcomes (Juzwishin 2009). In our case study patients enjoyed the social interactions at day hospice as that gave them an opportunity to share and discuss clinical and social aspects of their lives. Patients need to be able to replicate the social environment of programs like day hospice, even when they are in their own homes.

4.2.6 Knowledge Exchange Interoperability

Evidence-based medicine (EBM) is the conscientious, explicit, and judicious use of current best evidence in making decisions about the care of individual patients (Sackett et al. 1996). Providers often require access to evidence as part of care planning for a patient. Access to evidence is particularly useful in complex patient care such as palliative care. In our case study, having access to palliative evidence made family physicians more confident in managing palliative cases. The ability of patients to become active stewards of their own care will also require access to evidence. However accessing evidence can be challenging. Upwards of 30,000 scientific articles are published annually (Choi 2005) and thus retrieving timely evidence that is relevant for a patient case is challenging.

4.3 Mashup Patterns for the Interoperability Requirements

After analyzing the mashup patterns, described shortly in section 2.5.1, in the context of the interoperability requirements derived from our case study, we identified the harvest, assembly and testing patterns as best fit for meeting the interoperability requirements. Our rationale for selecting those patterns is described below.

4.3.1 Harvest Pattern

The harvest pattern is indicated for employing data from both structured and unstructured data sources. Examples of structured sources include RSS feeds and XML, and unstructured sources can be websites, Excel files, and even free-form text. However, mashups that employ unstructured data sources are more fragile in comparison with those which use structured data sources; therefore, it is very important to first consider structured data sources in order to maintain the stability and sustainability of our mashup-based environment. The harvest pattern is mainly for enhancing data interoperability and is therefore able to address the requirements of data interoperability (Section 4.2.1), where there is a need to monitor patients' current status automatically and instantly via possible communication channels, such as RSS feeds.

4.3.2 Assembly Pattern

The assembly pattern can be used in situations where there is an immediate need for a service or an application to address an issue. In other words, rather than going through the IT department and launching formal processes such as design and specification, the assembly mashup pattern can provide an opportunity for the layperson (e.g., a nurse) to easily and quickly create ad hoc tools and data streams for taking care of the issue on an as-needed basis. This pattern is also referred to as *integration on the glass*, where the user can quickly mash a component for a particular purpose without needing to change the underlying functionality or the infrastructure (Rayns & Jensen 2010). We believe that this pattern can be used to meet the requirements of team task and collaboration interoperability (Sections 4.2.2 and 4.2.4), where team members with varying skill sets and possibly from different locations need an immediate space, such as a virtual conference, to make decisions collaboratively with regard to a patient.

4.3.3 Testing Pattern

The testing pattern is mainly for realizing whether one method of addressing an issue in a mashup-based environment will be possible in the real world and whether it will be accepted by users. In this case, mashup tools can be used for creating a prototype, possibly by requesting a service from the Internet, and testing will be performed for proofing the original concept or idea. The testing pattern is especially useful for situations where there is not much interest in building a solution from scratch; instead, existing applications and services can be partly used in the current or new system for addressing an issue or requirement (van der Aalst et al. 2003). Through the testing pattern, the requirements of social interoperability (Section 4.2.5) can be met, where there is a need to examine whether replicating the social environment of day hospice with an online health social network is possible and whether it will have the expected positive implications on patients.

4.3.4 Other Interoperability Requirements

We were not able to use mashup patterns to facilitate policy and procedure or knowledge exchange interoperability (sections 4.2.3 and 4.2.6) in our framework. When we analyzed the mashup patterns against the interoperability requirements we realized those two types of interoperability would be challenging because of their volume and dynamic nature.

Generally, a major issue for interoperability of web-based services is the interplay between various policies, terms of service, and service level agreements (Gasser &

Palfrey 2007); and the same goes for interoperability of healthcare systems and health 2.0 applications. In the context of healthcare, a possible solution to address such an issue would be to adopt standardized healthcare policies and procedures, and have a concise way of communicating them among healthcare providers. However, more researches should be carried out to find out how and to what extend the healthcare policies and procedures can be standardized with the aim of improving healthcare interoperability at this level.

Chapter 5: Proof-of-Concept Implementations

To show proof-of-concept of how our mashup-based interoperability framework can address the interoperability requirements, we developed three proof-of-concept implementations in the IBM Mashup Center, which is an end-to-end mashup platform designed for both nontechnical users and IT personnel (Hoyer & Fischer 2008). This platform provides users with the key capabilities needed to quickly and easily create, share, customize, and secure enterprise mashups, widgets, and feeds. With IBM Mashup Center, organizations are able to reduce their application backlog and improve productivity by speeding application development process and encouraging reuse of applications and resources.

It is important to mention that the proof-of-concept implementations are based on the case study and interoperability types from chapter 4.

5.1 Implementation and Proof-of-Concept of Collaboration and Team Task Interoperability

Our framework supports collaboration interoperability as follows. A collaboration widget is made available by one of the caregivers through a Mashup Tool, and then incorporated into a mashup-based environment (e.g., IBM Mashup Center); this is where the central component and the integration/interaction mechanism component of our framework are used by one of the healthcare actors. Invitations for an online meeting are then sent to all the care team members by e-mail prior to the actual meeting. In emergency situations, a contact widget displaying the list of care team members with online status information (Sire & Vagner 2008) can be incorporated by one of the care team members into the mashup-based environment and invitations for an online meeting can be sent immediately to those with an online status. In addition, the skill sets of care team members can be shown in front of their online status (like Nurse #1: Symptoms Management Specialist) in order to be able to assemble the care team based on patient needs. Here, the name of each care team member can be hyperlinked to a dedicated blog for providing detailed information on their abilities and skill sets. Thus invitations can only be sent to the right health caregivers with the required skill sets (team task interoperability). The online meeting, or e-conference, provides an opportunity for care team members to discuss a patient's issues and make a decision collaboratively.

A snapshot of the proof-of-concept implementation of this scenario is shown in Figure 3. We describe the implementation of collaboration interoperability (Section 4.2.4) and team task interoperability (Section 4.2.2) by referring to the circled numbers in Figure 3.

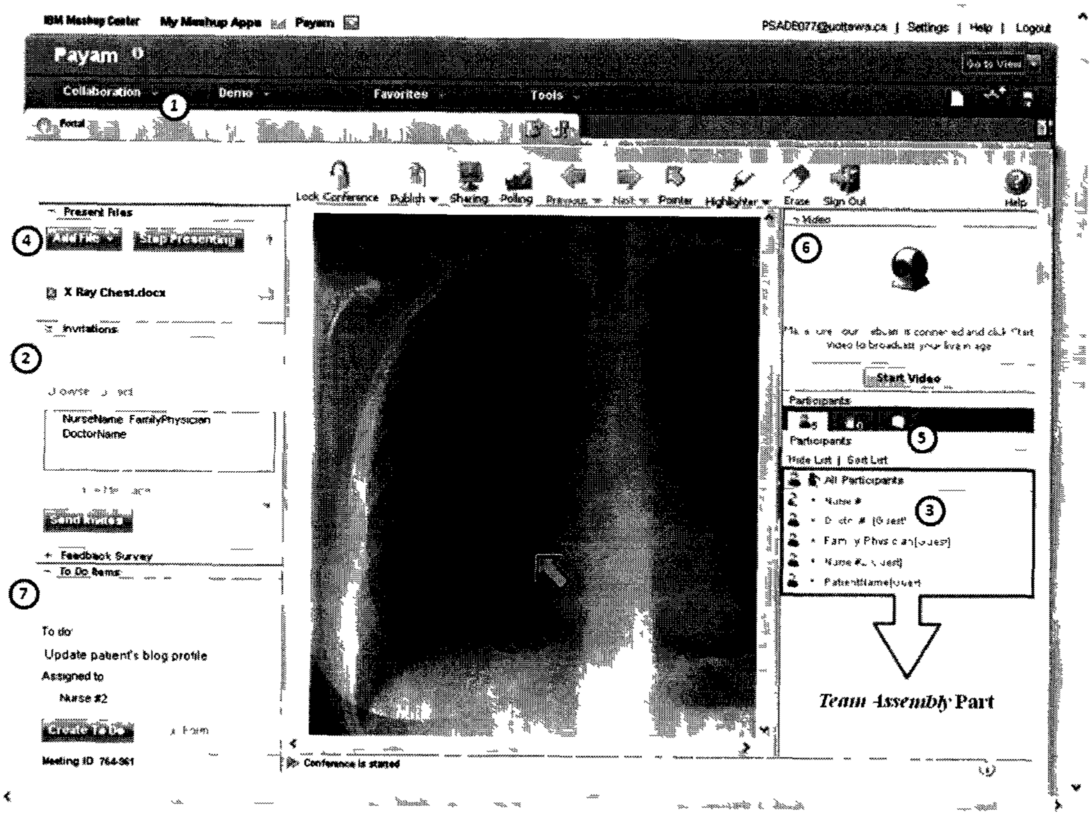

Figure 3. Implementation for Collaboration and Team Task Interoperability

(#1) The collaboration widget, called Portal, is incorporated (drag & drop) into the mashup environment and then the virtual online meeting, named IBM LotusLive, can be called by the Portal widget as an Internet-based service. (#2) The invitations for the online meeting are sent by the person who initiated the meeting (e.g., Nurse #1) to care team members. (#3) A list of the care team members who have accepted the invitation and are participating in the online brainstorming meeting. This feature also facilitates the assembly part of a team based upon abilities and skill sets. (#4) Participants can share and present files/documents which are relevant to the patient (e.g., an X-Ray scan of a patient's chest), in order to further discuss his/her condition and make decisions collaboratively. (#5) Discussions among participants can be done through the chat functionality. (#6) In case of a need for video conferencing (e.g., when the physician wants to observe the patient's facial expressions), a webcam can be used. (#7) Once the brainstorming session is completed and decisions are made, the person who initiated the meeting (Nurse #1) documents and creates a list of tasks to be assigned to each care team member, and then assigned tasks are sent by e-mail. The assembly mashup pattern was used for this scenario, where there was a need for an immediate virtual meeting with other care team members who are not located at the same place.

5.2 Implementation and Proof-of-Concept of Data Interoperability

Our framework can be used to meet the requirements of data interoperability (Section 4.2.1). A dedicated blog can be created for the patient where any changes in the status of his/her care plan (Cardex) together with relevant decisions made for each specific plan are posted by one of the caregivers (e.g., Nurse #1). By this, all the collaborative team members are able to check the conditions of the patient on a regular basis by referring to the patient's blog, and they can even contribute by leaving their comments on the blog posts, if needed. However, rather than asking the different team members to visit the patient's blog for checking new changes/updates in the patient's care plan, RSS technology can be used so that team members can subscribe to a patient's blog through RSS Feeds and then incorporate RSS Feed Reader/Viewer widgets into their mashup environment in order to receive notifications as soon as the blog is updated. In this case, the collaboration environment, the data source and the integration/interaction mechanism components of our framework are being employed. A snapshot of the implementation is depicted in Figure 4.

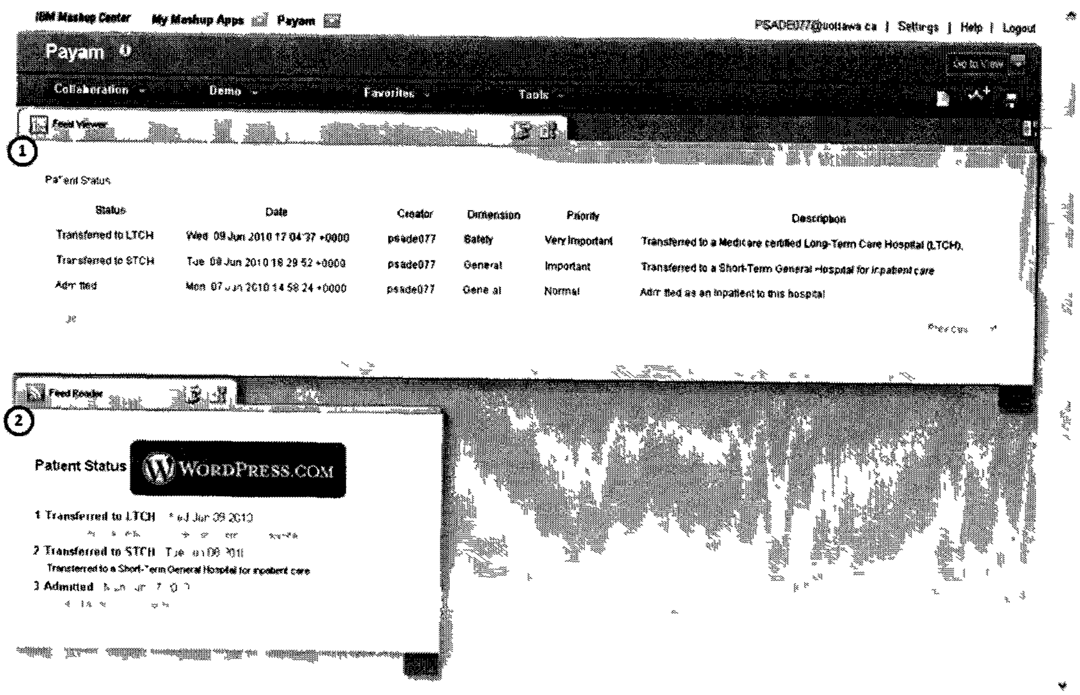

Figure 4. Implementation for Achieving Data Interoperability

We describe the implementation of data interoperability by referring to the circled numbers in Figure 4. The RSS Feed Viewer widget (#1) and RSS Feed Reader widget (#2) are incorporated in the IBM Mashup Center environment; the dedicated patient's blog (www.psade077.wordpress.com) is the data source of these two widgets. (#1) Pulls various data from the patient's blog and puts them all together in order to provide an overview of the patient's condition in terms of his/her recent status in different dimensions (e.g., Safety, General, etc.). This widget can be customized to meet the different needs of the different providers; for example, the widget can be customized in a way that in case of any urgent/important conditions, the patient's status is highlighted to attract the provider's attention. (#2) Shows the concise overview of the patient's condition and it can be customized such that in case of any changes in the patient's blog, notifications are received immediately by the RSS Feed Reader widget (Karkalis & Koutsouris 2006). Through RSS technology, mashup-based environments are able to dynamically incorporate content from external information providers since RSS data feeds are created using a structured format (XML) and therefore mashups can easily consume them as a data source (Ogrinz 2009). This may also enhance interoperability at the data level considerably. As a result of using blog and RSS technology, care team members are able to observe the overall treatment process in real-time together with seeing how the information is distributed among them; which may increase the transparency of the treatment process (Hoegg et al. 2006). The harvest pattern was used in this scenario with RSS feed as a communication channel for monitoring the patient's current status.

5.3 Implementation and Proof-of-Concept of Social Interoperability

The third scenario implements the requirements of social interoperability (Section 4.2.5). As mentioned previously, patients should be able to replicate the social environment of the day hospice. For this purpose, health social networks can be a solution. They are primarily directed at patients but other healthcare actors can participate and have direct interactions with patients and provide them with further help and assistance, if required. Figure 5 is a snapshot of the implementation of social interoperability using a health social network called *PatientsLikeMe* in the IBM Mashup Center. We describe the implementation and proof of concept of social interoperability by referring to the circled numbers in Figure 5.

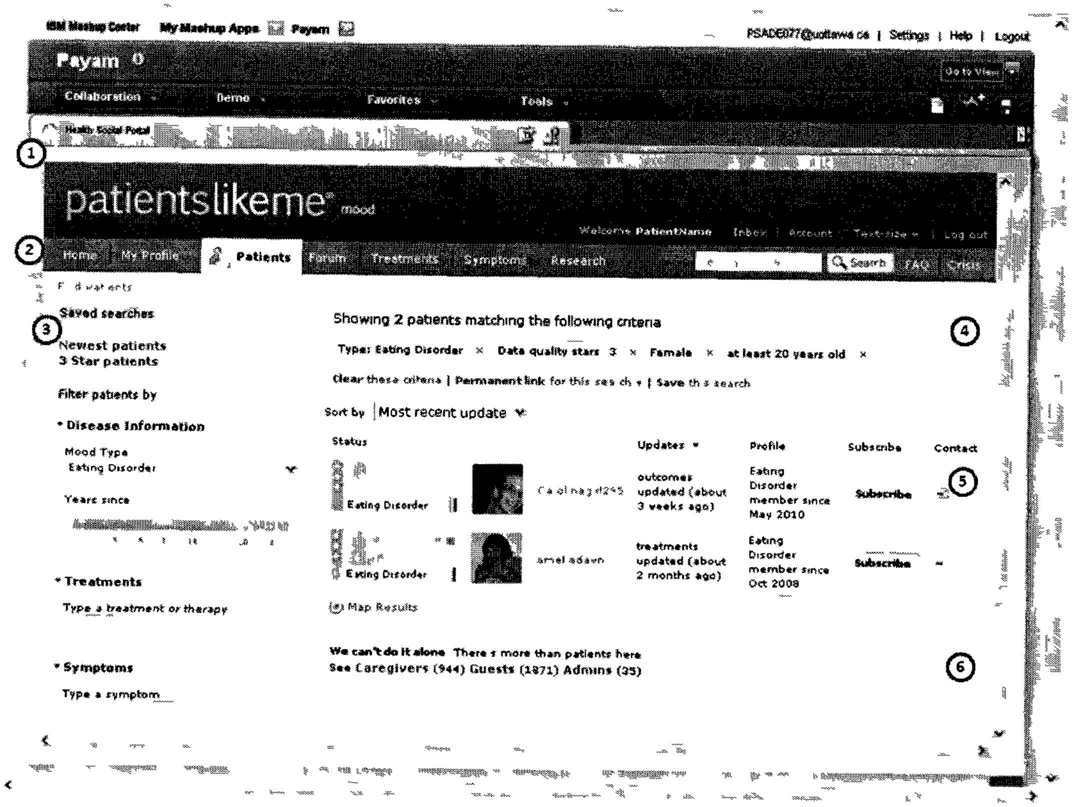

Figure 5. Implementation for Achieving Social Interoperability

In order for patients to have such a service in their mashup, they may refer to the Collaboration tab, then add the Portal widget (#1) into the IBM Mashup Center, and then call the PatientsLikeMe social network. This is where the central and integration/interaction mechanism components of our framework are utilized. (#2) enables the patient to create his/her profile. (#3) helps the patient to search for other patients with a similar condition, ask questions and share personal experiences in the forum and browse treatment/symptom reports and advice. (#4) allows the patient to search for information on health conditions and treatments. (#5) shows the results of a customized search, where the patient sees those who are in similar conditions as him/her, and is able to contact them directly and view their profiles. (#6) is where the patient is able to interact with other caregivers in order to gain further support, and pose questions about his/her condition (Bos et al. 2008). The testing pattern was used for this scenario to implement social interoperability.

Since the privacy of the patients and patient's data in any social health networks is quite important for all the actors of healthcare process, especially for the patients themselves, websites similar to PatientsLikeMe provide a possibly for their users to define their privacy level. For this purpose, users are able to set their privacy level as *visible* where only registered members are able see their profiles, or as *public* where non-members are also able to view their profiles. Patient members and their healthcaregivers may provide as much or as little information as they want and they are *not* obliged to enter any information they feel uncomfortable sharing. In addition, in order to establish trust relationships among healthcaregivers and patients, healthcaregivers are entitled to enter their affiliation (PatientsLikeMe 2009), which will be displayed within the website. By this, patient members feel comfortable when they are contacting the healthcaregivers for sharing their information and getting advices in regard to their health conditions.

5.4 Implementation Challenges

The core components of our interoperability framework (Figure 2) together with the mashup patterns behind them are able to provide an interoperable framework for communications between people, data and applications. However, we identified several systems design challenges for implementing such architecture. The primary challenge is that it requires flexibility in design since the collaborative needs of healthcare systems are complex and dynamic. Healthcare teams vary from case to case and the level of information exchange and collaboration that is necessary for care delivery will also vary. Therefore, there will need to be multiple implementations of the framework depending on team needs. Similarly, patients will have different needs and that will also require system design flexibility.

In order to support systems design that allows flexibility of structure and features, an iterative and user-centered systems development method should be used. In order to streamline the development process, visual mashup development tools, like the IBM Mashup Center, could be provided to end-users where various features and simple composition approaches are available for selection and biding. The usability of the mashup environment defines the skill set that the user needs to have in order to start using it (Beletski 2008) and therefore, usable and friendly mashup tools should be provided to users in order to improve usability, interactivity, and acceptance. As a result of involving the main actors of healthcare processes early in the design phase, a more effective and usable system can be implemented (Pilemalm & Timpka 2008). In such a bottom-up approach, where patients and other actors of the healthcare process are the actual creators of healthcare services and applications, patients are considered as partners and their expertise is greatly valued, and other actors are able to directly examine which applications are being incorporated by the patients in order to better understand and anticipate the patients' needs and consequently provide them with sufficient ways of performing a task or using a service.

The following iterative process (inspired by (Cel'Amanzi Oy 2008)) can be considered for the development of the proposed framework:

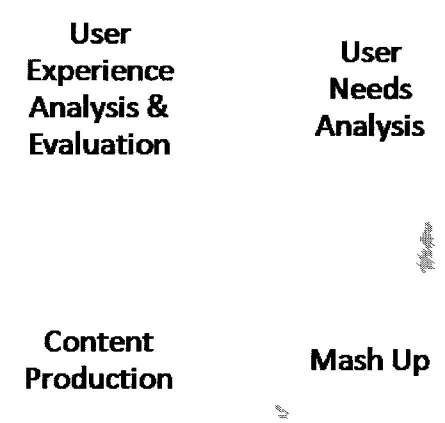

Figure 6. Iterative User-Centered Development Process

As shown in figure 6, the iterative design process consists of four phases described as follows:

- **User Needs Analysis:** At this phase, the preliminary requirements and specific needs of users are identified and documented in details. These include their information needs, values, preferences, data types, services, and possible required support; with regard to patients, information of their physical and health conditions as well as some information about their family and friends. Since a large amount of information is being gathered and analyzed at this phase, we recommend that all the actors who provide information values to users be involved throughout this process. For example, for patients, the following actors should be considered for better realizing the patients' needs: healthcaregivers, healthcare providers, supporters and insurers.

Afterward, the existing Web 2.0 technologies, which can be used to implement different functions for satisfying users' identified needs, are being discussed with users in a simple and understandable language. That is where users are practically considered as partners in the design of the healthcare environment. By this the healthcare environment, which is being developed by users, will be regarded as useful since its technologies and components are being defined during their default state, and user engagement will be improved significantly (Alexander 1979). It is important to mention that at this phase, face-to-face interviews, online chatting, surveys, and cultural probe methods (Hassling et al. 2005) can be used to communicate with users for establishing their basic requirements and sufficiently understanding their needs.

- **Mashup:** This is the actual composition phase where users utilize a dedicated and easy-to-use mashup development tool for mashing up the recommended and required components, as defined in the previous phase. Here users are able to drag-and-drop the components and interactively configure and customize the components' layout according to their personal taste and preferences. In this phase, support with regard to clarifying the components and services to users is basically essential and therefore those actors who provide information and/or intangible values to users should be involved throughout the composition process. With regard to patients, healthcaregivers and healthcare providers are the ones who are required to directly assist the patients during the process. In order to make the environment more adaptable to users and improve its value, users can be provided with a set of similar and dissimilar components in order to be able to substitute them on an as-needed basis (Germonprez et al. 2007), and by this, users integrate specific and reusable components in order to create a unique healthcare environment. As Pask argues (Pask 1971), users may enjoy this process due to the fact that the environment and the technologies, which they are using and configuring, are being designed to support their needs and requirements; therefore they are achieving their goals through technology. In order to streamline the mashup composition process for users, easy and simple exploration, organization, and integration of components or services should be provided (Yu et al. 2008), and therefore different Web 2.0 technologies are being easily combined to enhance the mashup capability (Cheung, Yip et al. 2008).

- **Content Production:** As a result of the previous phase, each user has a personalized environment where the preliminary components have already been integrated, and in this phase information is being tailored to users, based on their defined particular needs and preferences, through multiple content providers and diverse data sources, as shown in the Figure 2. In this phase, users either work with existing content or create and manage their own content; and users may create content individually or in collaboration with other actors. For example, patients with chronic diseases receive news, articles, and information about their condition from data sources of their choice, or from their healthcaregivers; or personalized information, articles, or advice related to patients' condition are generated by correlating information from patients' health records in order to inform patients or healthcaregivers (Karkalis & Koutsouris 2006). Various pieces of information, such as discussions, chat histories, images, documents or files, are being produced in this phase, but there is a requirement that all this information is provided in a way that allows users to determine its credibility and validity with full transparency regarding the source of the content. Therefore effective procedures and contribution policies should be in place in order improve the quality of provided information and knowledge sharing (Wright et al. 2009).
- **User Experience Analysis and Evaluation:** In this phase, users' experiences of the healthcare environment together with different aspects of the system are

analyzed and evaluated. The aim of this phase is to realize whether the fundamental users' needs and values are supported by the system (Väänänen-Vainio-Mattila et al. 2008), and therefore user experience should be a key concern here in order to refine the iterative development process. In this phase, all the actors of the healthcare process should be involved in order to reflect different perspectives and opinions on each others' experiences, and also to check whether their experiences match their original goals and needs. In addition, the functionality of integrated components and the level of user engagement should be evaluated adequately. The WebMedQual guideline for website assessment contains constructs for the assessment of information content, the authority of source, accessibility, links, user support and privacy (Provost et al. 2006), which can be used a tool for further analysis and evaluation of the developed environment. Based on the outcomes of the evaluation and users' feedback, effective methods should be applied in order to revise and develop the users' needs and to better proceed with the iterative process. It is important here to let the users establish, prioritize and verify the requirements (Boehm & Turner 2003) and rely on their knowledge for capturing and documenting the new requirements.

We believe that by following the above iterative user-centered approach, great improvements to the development of our proposed framework will be achieved and important issues and new ideas may arise which could be considered throughout the iterative process.

Chapter 6: Discussion and Conclusion

Interoperability is set to become a key driver of healthcare delivery. As more care delivery is provided via collaborative teams it will increase the need for integration of data, people and processes across different settings. To date much of the research on healthcare interoperability has focused on technical and to a lesser extent semantic interoperability, while process interoperability has been largely ignored. However, healthcare delivery takes place at the process level and we need to understand and support interoperability from the perspective of healthcare processes and most importantly, the people who conduct these processes.

To provide insight on that challenge, this thesis has extended existing research on healthcare interoperability by studying collaborative care delivery and the processes that take place within it. We used a palliative care case study to identify a set of interoperability requirements that were focused on *the processes needed to support collaborative care delivery*. We then used the case study to develop a mashup-based framework for multi level healthcare interoperability. The framework facilitates flexible, useful and effective user interaction and management with all kinds of data sources, and targets all the actors of the healthcare process; therefore, it can be seen as a real collaboration framework specifically designed for healthcare environments. We believe that our framework provides the foundation for supporting process interoperability by consolidating web 2.0 technologies, communication channels and data sources in a single environment. Finally, we introduced mashup patterns for facilitating interoperability within the framework. We also implemented three scenarios to provide proof of concept of how our framework and mashup patterns can be used for developing a collaborative healthcare environment. In summary, our proposed framework mainly automates the following processes which are considered as part of the healthcare process interoperability:

- **Information sharing:** Sharing information related to patients' status and conditions among healthcaregivers in a timely manner together with providing instant information regarding changes with progression of patients' diseases (e.g. appetite, hydration, etc.), through technologies such as RSS Feeds (and tools like Twitter), where instant updates can be posted by one of the healthcaregivers to the other ones who already subscribed to the RSS Feeds for receiving such updates.
- **Team-task recognition:** Determining the professional care team who should lead and coordinate the functions and activities of the team, based on the patient's condition and requirements, through technologies such as health social networks and online conferences (e-conferences), where all the

healthcaregivers have an *online profile* showing their expertise, background and affiliation in order to form the professional care team easier and faster.

- **Collaboration Process:** Facilitating communication of the plan of care to the healthcaregivers and direct collaboration among the healthcaregivers through technologies such as blogs, wikis, online chat and conferences, where multiple online meetings can be held in order to discuss the plan of care and then document them in form of blog/wiki posts.
- **Social Interaction:** Encouraging the patients and healthcaregivers to communicate and interact with each other to further discuss their issues, possibly prioritize the importance of each of the identifies issues together, and get emotional support from each other, through technologies such as health social networks where patients are able to find those who are in the same condition as they are, and both healthcaregivers and patients are able to interact with each other to discuss their issues.

Even though we have automated some processes of the collaborative care delivery, as described above, there are still some other processes that our proposed framework does not automate as follows:

- **Healthcare Policy and Procedure:** Online policy and procedure management help healthcare organizations to effectively and efficiently advance patient care, coordinate and track the dissemination of policies, and eliminate outdated/duplicate information. However, our proposed framework is not able to facilitate the interoperability of healthcare policies and procedures due to the fact that it is challenging for web-based services to function between various policies, terms of service, and service level agreements which are coming from different healthcare organizations and institutions.

- **Healthcare Knowledge Exchange:** Developing a problem-solving collaboration environment for healthcaregivers is necessary in order to enable them to exchange healthcare knowledge unrestricted by time and geographical barriers which would also reduce knowledge transaction cost and would also facilitate the process of producing new knowledge. Although our proposed framework is able to provide a possibility to exchange healthcare information, but due to the volume of healthcare information and knowledge, facilitating such a requirement is still challenging. A possible solution would be incorporate healthcare wikis in our proposed framework, but further research and evaluation, especially by the main actors of the healthcare process, is required.

The novelty of our work resides in the fact that not enough attention has been paid to process interoperability and how to achieve it. To the best of our knowledge, this thesis is the first research that has used mashup technologies and patterns to achieve interoperability at the process level. We suggest that understanding those technologies and patterns will trigger new ways of thinking about interoperability and how we can build new solutions to support it. The key message from this thesis is that designing technological artefacts for healthcare requires interoperable systems and interoperable people who will use the systems. Therefore, a shift from a technology-driven implementation to one that is driven by an understanding of how people, technology and process interact is needed. Therefore, in order to design an interoperable healthcare environment, we should have a thorough understanding of the technology, in our case mashups and their patterns, and how that technology can address unmet interoperability requirements at all levels including data, team, social and collaborative levels. In addition, interoperability at the process level greatly depends on willing participation of healthcare actors throughout the healthcare process together with compatible healthcare policies and procedures.

This thesis has also extended interoperability research by providing a methodology for identifying interoperability requirements in healthcare settings. We added a data analysis method, in our case qualitative content analysis, to the design science research method to analyze and identify interoperability requirements from clinical data (based on observations and interviews). Content analysis provided a rigorous data analysis approach to help make sense of the complexity of collaborative care delivery and the interoperability requirements needed to support it. The hybrid method used in this research allowed us to understand both the technical and behavioural (i.e., process, collaborative, social) aspects of health information technology.

This thesis also provided a set of six interoperability requirements that focused on process interoperability which can be considered as the answer to our first research question declared in Chapter 1 (What are the healthcare interoperability requirements for collaborative care delivery?). The requirements can be used as a starting point for identifying process interoperability requirements in other settings. The requirements also demonstrate the breadth of processes that are part of collaborative care delivery. Through our mashup based framework we provided implementation and proof of concept of four of the six interoperability requirements. As described earlier, policy and procedure and knowledge exchange interoperability were not implemented because of the challenge posed by the dynamic nature of these two types of interoperability. Further research is needed to develop solutions for facilitating policy and procedures and knowledge exchange interoperability. Therefore, the answer to our second research question declared in Chapter 1 (Can a multi-level mashup-based framework be developed to meet these requirements?) is positive since almost all the identified interoperability requirements derived from the case study can be met by our proposed multi-level mashup-based framework except policy and procedure and knowledge exchange interoperability requirements. Our proof-of-concept implementations showed that collaboration and team task interoperability can be met through collaboration widget, or portal, which basically is part of the IBM Mashup Center; data interoperability can be met through incorporating RSS Feed widget in the Mashup environment; and social interoperability can be met through incorporating a health social network, like PatientsLikeMe, in the mashup environment.

In addition, we recognize that security and privacy requirements have to be considered when implementing our framework in clinical settings due to the fact that a secure infrastructure is important for the operation of any virtual healthcare community, and it is critical to protect the confidentiality of sensitive medical data (Chryssanthou et al. 2009).

Limitations of our research and this thesis are that the interoperability requirements and mashup-based framework were derived from a case study in one setting. Other interoperability requirements and the mashup-based technologies to support these requirements may emerge in other settings. Another limitation is that we have not formally evaluated our framework. Future research should involve formal evaluation of the proposed framework and mashup patterns in different healthcare settings. For this purpose, the framework and the proof-of-concept implementations can be evaluated by including the real users in the process, such as patients and healthcaregivers, and asking them to fill out survey forms to describe their experiences with such solutions. For example, in order to provide further proof of concept of replicating the social environment of a patient at day hospice, the patient's experience with the health social network needs to be formally evaluated in survey form (usability testing).

Another limitation is that we implemented our framework using one specific mashup tool (IBM Mashup Center) and other tools exist for developing mashup based environments. Future research should also involve implementing our framework using other mashup tools.

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