Computational Ecosystems in Home Health Care

Rune Gustavsson, Martin Fredriksson, Christer Rindebäck

Department of Software Engineering and Computer Science,
University of Karlskrona/Ronneby,
S-37225 Ronneby, Sweden.
email: rgu@ipd.hk-r.se, mfe@ipd.hk-r.se cri@ipd.hk-r.se

Abstract. The focus of this paper is to evaluate how to appropriately apply information technology and computational ecosystems in electronic health care without sacrificing the quality of service. We conduct this evaluation by introducing two scenarios (Smart Care and Home Dialysis) and a trust enforcing model (ORA). Furthermore, a system design for a trust enforcing ecosystem is also introduced (SOLACE). The evaluation described in the paper aims at clarifying the need for institutions (as we perceive them in human societies) to be implemented as a fundamentally important part of computational ecosystems that are grounded in both the real world and a virtual environment.

1 Introduction

Social interaction concepts such as norms, commitments, obligations, rights, permissions, responsibilities and so on have been studied from different points of view in the area of multi-agent systems. Many of these studies have focused on different aspects of electronic commerce. However, recently a new and important area for applied information technology has emerged - electronic health care. The focus of this area is how to use information technology in order to cope with an increasing demand of health care and at the same time manage the increasing costs in the social and health care systems without sacrificing the quality of services. In Sweden, as elsewhere, the possibilities of information technology in electronic health care is evaluated in several national programs. The University of Karlskrona/Ronneby is involved in two national projects related to these programmes: Smart Care and Home Dialysis. Focus of the Smart Care project is on smart homes built around the needs of elderly people or people with special needs. The Home Dialysis project focuses on the possibilities of managing dialysis at home. Needless to say, in both these cases the acceptance and hence the usefulness of project results are due to aspects of a very non-technical nature. Issues such as responsibilities and trust are in the foreground for an acceptance of services required by patients. It is also inevitable that the introduction of information technology-based versions of these services will change how the health care providers will operate and how their personnel are trained. In the Smart Care project new information technology will enable the creation of an ecosystem around the caretaker. That is, the information created around and by the caretaker has to be gathered, processed and distributed in a way that makes life for the caretaker both safer and worthwhile. In the Home Dialysis project, tasks currently performed at hospitals is transformed into tasks performed at the premises of the patients. Obviously, issues such as responsibilities and trust has to be addressed and empowered by the technical solutions at hand. In both these cases we have to address the role of culture as a fundament behind issues such as norms. In the paper we outline an information system architecture supporting investigations of important issues concerning electronic health care systems. We have also identified key concepts such as ownership, responsibility, and accessibility (ORA) which we argue are building blocks in creation of trust relations.

2 Scenarios and Experiments

A fundamental issue in health care is trust. That is, a person has trust in another person to successfully perform a task in a given context. In our case the trust is often related to a person acting in the context of institutional power, i.e. a nurse in a hospital. Trust is also often connected to responsibility. In a hospital we trust the quality of treatment because we can see and accept a certain chain of responsibilities. However, a basic question: how can we develop and implement information systems that allow us to have trust even in health care partly constituted by a supporting information system? Figure 1 highlights important aspects of this type of health care systems. Firstly, care taking processes can take place in three different locations; at home, in hospitals or in between. In the latter case it could be in an ambulance or other transport or at another institution such as a local health care or activity centre. Secondly, the figure points out the importance of institutional culture associated with health care measures. Thirdly, the figure highlights the importance to ground the information system (e.g. a virtual world) in the real world. Later on, in a design example of a computational ecosystem (see section 6) we make use of entities in the virtual world to reflect both notions and behavior corresponding to smart equipment, services, or people in the real world. Important connections between the real and the artificial worlds are provided by ownership, responsibility, and accessibility relations. A closer look at two electronic health care scenarios reveals a set of challenges to address and resolve before we can implement the new models of health care.

2.1 Home Dialysis Scenario

Presently, dialysis sessions are mainly performed in hospitals. Patients have to visit the hospitals on a regular basis, several times per week, and spend many hours at the hospital each time. Needless to say, this is a costly and time-consuming model of treatment. Due to technological advancements there are now possibilities to allow patients to be treated at home. Different models to electronically connect the patients' home with the hospital are tested at the moment. From a trust perspective there are, however, several open questions emerging from the present hospital-oriented work habits. Firstly, patients that are treated in hospitals are by and large seen as passive objects undergoing treatment from the perspective of the hospital personnel. Secondly, in hospitals there is a responsibility-chain based on locality in space and time. Thirdly, patients that are treated in a hospital have a well-defined care provider (in Sweden, primary health care organizations). In a home based dialysis situation none of those three fundamental assumptions are valid. Thus, from the perspective of an institution (e.g. a hospital) we might encounter several types of changes and challenges, such as: distribution, expansion, and creation (for a more detailed description, see section 4). We are currently working with the first and third type of change. For instance, we believe that the patient has to be responsible of parts of his treatment at home. The possibilities of shared responsibilities between institutions and the care taker are, we believe, fundamental. But we must also include new responsibilities from home care units (in Sweden, secondary health care organisations).

2.2 Smart Care Scenario

In this project we address another aspect of electronic health care. Again, due to an aging population, there is a need to allow elderly people to continue living in their homes as long as possible. The suggested approach is to allow people with special independent living by offering the necessary support. Advances in information technology enabling, a new way of living, come in two strands for this type of people. Firstly, we have the technology to support smart homes and to connect smart equipment and people in networks. Secondly, we have advancements in nano-technology providing us with completely new means of monitoring and supporting life-critical processes in the human body. These measurements can then be communicated to the outside world, or be used by local actuators. In short, we have environment- and human-centric information networks that can interact. In the national Smart Care project we are addressing these types of networks, starting with the two sub-networks. Evidently, in order to cope with this type of complexity, we have to create a scalable institution, or ecosystem, centred around the care taker. Again, issues such as ownership and responsibility of services and accessibility of information are crucial concepts supporting trust in this type of systems.

2.3 Experiments

Health care can be viewed as an institution (e.g. a hospital) that owns a number of entities (health care functions). Furthermore, these entities provide certain services to a number of users (patients). This perspective on the hospital as an institution can be considered to be of a localized nature, i.e. the patients are situated inside the actual hospital and are taken care of by the hospital staff themselves. However, as we have previously described in the home dialysis and smart care scenarios, a need to move the patients from the hospital to their own homes has started to emerge. This emergent change of the hospital as an institution require that we change our perspective on things, in a quite radical manner. At least when it comes to the implicit consequences concerning concepts such as trust, ownership, responsibility, and accessibility.

We envisage a new model of the hospital as being of an adaptive nature, i.e. the institution must be able to cope with the fact that patients would no longer be physically located at the hospital, but rather in their own homes. What we are primarily aiming at is an institution that successfully is able to transfer the notion of trust that a patient would have in the services provided by the traditional notion of a hospital into the new model of an adaptive institution. In this model, the hospital is still considered to be an institution that owns a number of services that offers health care functions to the patients physically situated in the hospital. However, the adaptive institution must also be able to provide the "remote" patients with some sort of health care functions. Hence, there are basically three questions we should try to investigate:

- Which health care functions can a hospital supply remote patients with?
- Which health care functions can a remote patient take care of?
- In what way can the resulting ecosystem address the concept of trust?

Obviously these primary questions make a number of other issues come to surface. For example, a direct consequence of both the first and the second question is that at some point, when it comes to the complexity of a required health care function, a patient can no longer be placed in his or her own home. Furthermore, another consequence of these questions is that a patient must be responsible for some of the health care functions (previously performed by the hospital presonnel). We wish to answer the questions above and conduct a more in-depth analysis of their consequences by future experiments based on the SOLACE platform. These experiments also require a system design of the actual implementation - a computational ecosystem focusing on the health care of a patient and the involved institutions and health care functions.

3 Trust and Institutions

The concept of trust is a crucial concept in computational ecosystems [1]. The concept of trust primarily relates to four issues: commitment to rules, frequency of positive exchange between two entities, propagation, and context experience. In this paper we will mainly focus on commitment to rules, since it is very much related to the notion of power and purpose of institutions. In order to create trust in a relation between two entities it is imperative that both entities acknowledge their commitment to the rules of the system authorities, i.e. they are aware of the fact that service exchanges of a negative nature are not tolerated by the system authorities. These system authorities correspond to what we would denote as the primitive institutions of the system, i.e. all entities in the system trust these institutions and their roles in upholding the stability of the system. Therefore, commitment to the rules defined by the institutions can possibly be seen as the necessary price to pay by the entities in order to be certain that there are at least some entities in the system that always can be trusted. We call this basic approach of trust enforcement in a system institutionalized power, i.e. in exchange for some parts of the freedom of an entity it is assured that there is some other entity in the system that it can trust to look after its interests. An example of institutionalized power can be found in institutions of our society, such as the Swedish national bank. Through proper delegation of authority we can trust a civil servant to perform a certain task for us, e.g., we accept banknotes from a clerk in a bank office as a payment of a check. We can trust an agents ability and willingness to perform a task or we can have trust in the reliability of the information transmitted. We model the concept of trust in institutionalized power as a 4-place relation, see Equation 1. There are several attempts in giving a formal treatment of and providing semantics for such types of trust relations [4]. In the context of an institution a task is typically performed by some entity, and thus, we conclude Equation 2 as the implicit trust relation involved.

$$trust :< person, person, task, context > \tag{1}$$

$$trust :< person, entity, task, value - chain > \tag{2}$$

The trust relation in Equation 2 corresponds to our everyday trust of an automatic teller machine (ATM) in the wall of a bank building, where we insert our ATM card and provide our pin code and accept the paper money eventually delivered from the machine. We trust that the money are valid and that the transactions are reliable. The trust relation has to be earned and can not be engineered in a system. However, by clarifying concepts such as ownership, responsibility, and accessibility (the ORA model) of an entity we can support different models of trust enforcement mechanisms concerning institutionalized purpose and power [2]. The ORA model strives to address all of these issues in terms of ownership conditions, responsibility contracts, and accessibility manifestation and communication.

3.1 Ownership

One important aspect of trust is that it implies a relation between a person and an entity (Eq. 2). The entity referred to in the relation is an embodiment of a concept (e.g. a service) that exists in a virtual environment. Furthermore, between a person and an entity there must also exist a condition that proves the validity of the ownership. There are many different ways of enforcing this relation. We suggest that one way of handling the enforcement of this relation is to focus on who actually owns an entity in the real world. The concept of ownership renders itself as a certain relation:

$$ownership :< person, entity, condition > \tag{3}$$

3.2 Responsibility

The concept of ownership in the ORA model is obviously of great importance, since without it the notion of trust a user puts in an institution and its constituents will be difficult to enforce. However, by incorporating ownership as a key concept in the ORA model it is also very important that we introduce another concept that is tightly coupled with ownership, namely responsibility. The reason for this is that if an entity is not owned by anybody, its responsibilities towards an accessing party in a societal setting cannot be enforced in a legal fashion. The issue can be perceived from two different perspectives. The first perspective is that of the owner of an entity. He or she offers a set of information or functionality to an accessing party using the entity in question. The owner of the entity has the right to require a mutual understanding in the form of a contract. The contract outlines the responsibilities of the entity (and consequently also the responsibilities of the entity owner). If the entity in question does not fulfill its responsibilities in accordance with the contract the negatively affected party has the right to take legal actions. The second perspective is that of the user of an entity. The user is willing to access a set of information or functionality offered by a second entity that is owned by someone. However, due to the fact that there is a possibility that the actually accessed set of information or functionality does not match the offered set of information or functionality, a contract is required between the user and the owner of the accessed entity. As a consequence of these two perspectives the concept of responsibility can be viewed as a relation between two entities (that are owned by two different persons) in the form of a legally binding agreement:

$$responsibility :< entity, entity, contract > \tag{4}$$

3.3 Accessibility

The two concepts of ownership and responsibility can be viewed as the cornerstones in the ORA model concerning the support for trust enforcement mechanisms. However, yet another fundamental concept needs to be considered in order to enable ownership and responsibility, namely accessibility. If an entity is supposed to access another entity there are two important issues involved that have to be properly handled. Firstly, in order for one entity to access another entity, there has to be some way for the first entity to address the other entity. An entity can offer a set of information or functionality that could possibly adhere to many different contexts. Therefore, all entities make use of the manifestation concept in order to address other entities. The concept of manifestation is twofold, it refers to the fact that an entity actually exists, but also to the fact that an entity in some way must be possible to perceive by other entities inhabiting its environment. In the ORA model, an entity is perceived by other entities as a description of the various concepts it supports. Secondly, once an entity has found another entity it must know the nature of its interface in order to be able to communicate with it. Since an entity makes use of manifestation as a way of finding other entities it is not clear what interface a newly found entity makes use of. The only way to solve this issue is that all entities agree to make use of the same primitive communication interface, no matter what manifestation they have chosen to make use of. Thus, in order to support the concept of accessibility in a computational ecosystem it is important to realize that manifestation and communication are fundamental parts of the relation between two entities:

$$accessibility :< entity, entity, manifestation, communication > \tag{5}$$

4 Institutions in Change

The introduction of electronic service mediation in commerce, business, and health care (i.e. the introduction of corresponding electronic institutions) pose a challenge of change in “the ways things are done here” and hence also a challenge when it comes to overall maintenance and creation of trust concerning the new services provided. For example, when ATMs were embedded into the physical walls of bank buildings, this enforced the institutional power of the banks. The physical embodiment of the new service, simplified the trust and acceptance of the new service since it was an obvious (physical) connection to a trusted institution. However, our Home Dialysis scenario is fundamentally different. For example, we have a transition from a centralized institution to a distributed institution, coupled with a redistribution of tasks and responsibilities. Since trust is a holistic concept that can not be subdivided or allocated to subparts of the involved services/devices, we have to recreate trust in the distributed institution. Often this comes down to starting with a reassessment of tasks and roles in the original institution prior to any new distribution of tasks and roles, and prior to assignments of tasks that can be electronically supported in the new distributed institution.

In the Home Dialysis example the original institution is a hospital to which patients comes regularly for their dialysis sessions. The new distributed institution consists of parts of the hospital, parts of a local home care provider and parts of the care taker’s home. A major reason behind the introduction of home dialysis is that a patients quality of life can be greatly improved in most cases by enabling more frequent but shorter dialysis sessions, compared to the normal case where we have a continuous mode of operation! In our case, a first attempt by the hospital to introduce home dialysis was to install dialysis equipment as well as a quite advanced video conferencing system in a home. This solution turned out to be a failure, mainly due to three reasons. Firstly, it was difficult for the nurses at the hospital to take responsibility for tasks they did not control locally. Secondly, the patient did not have trust in the treatment despite he/she could have a tele-presence of the nurses. Thirdly, in the end a nurse had to visit the patient regularly, which increased the costs of the treatment. This example also illustrates a difference in tele-medicine tasks, such as operations on a distance, and home dialysis. In the former case we have a situation similar to the ATM example above. In the latter case we have to change the institution into an ecosystem supporting electronic health care with trusted services.

A closer assessment of the culture and tasks associated with dialysis in hospitals revealed the following. As a preparation of a dialysis a nurse performs a set of different tasks, among them she takes a blood pressure test and weights the patient. Often she also pinches the patient gently. It turns out that these tasks are performed in order to determine the "wet-weight" of the patient, e.g., to decide how much dialysis to perform in order to get the "dry-weight" of the patient. As a part of the culture in hospitals there is a rather strict order of roles and responsibilities in the tasks performed. One of these norms is typically that the patient has the sole role of being treated with no obligations or responsibilities. In our case it turns out that a patient can learn his "wet-weight" and thus know how much dialysis he or she needs. Given this knowledge the patient will most often be confident enough to take responsibility of this task him- or herself. In our situation we have thus found a set of tasks that can be difficult to perform over a distance, since the actual body of the patient is involved. Furthermore, as a result from proper training, the patient can in many cases take responsibility for certain tasks, which in turn increases his/her trust in the possibilities of home dialysis. During dialysis, the most critical situations occur when the patient has a sudden drop of blood pressure. In that situation the patient needs the assistance of a nurse in order to manage the dialysis. Clinical tests shows, however, that this kind of problem is mainly due to stress felt by the patients. Again, an educated patient in a home situation is very unlikely to experience this kind of problem.

$$institution :< people, tasks, roles, culture, context > \tag{6}$$

$$context :< institutionpurpose, powerrelations, norms, locations > \tag{7}$$

$$task :< ownership, responsibility, accessibility, purpose > \tag{8}$$

As a result of the previous discussion, but also as an attempt of formalization, we model the concept of an institution as a 5-place relation involving people, tasks, roles, culture and the context of an institution (Eq. 6). Furthermore, in order to clarify the notions of context and tasks we model those concepts as two 4-place relations (Eq. 7 and 8). Please note that "context" in Eq. 6 and 7 refers to the context of the institution. In summary, preserving the trust in institutions and associated services, when they are transformed into ecosystems, can be quite challenging. For instance, consider the following possible types of institution changes:

- *Distribution.* The distribution of an institution typically imply an expansion of business at new sites or focusing parts of the core business to different locations, i.e., distribution of location in the context relation above. Trust is enforced at least initially due to the positive meanings of (successful) expansion or (quality assuring) focusing.
- *Expansion.* The expansion of an institution typically means an introduction of new services. The acceptance and trust of the new services mostly depend on how strongly related the new services are to the power relations of the institution.
- *Creation.* When different aspects of institutions aiming at the same market are combined a "hub" or "portal" is created. An example of such portals can be found in the home dialysis ecosystem, in focus of this paper. Ecosystems also typically evolve during time. Institutions and/or services might come or leave as new value-chains are created or changed.

We can not expect any structural mapping from trust in the services provided by an institution to the case where we distribute the institution and its related services. As we have illustrated in our home dialysis scenario we typically have to carefully reassess tasks and culture in the original institutions before we attempt to redistribute and coordinate the involved tasks. Furthermore, in order to support trust in the ecosystem we have to localize responsibilities in order to minimize "responsibility-at-distance". Hence, the concepts of responsibility, ownership, and accessibility (ORA) are crucial in distributed institutions and are therefore the core theme of this paper.

5 Computational Ecosystems

According to our previous definitions concerning institutions, contexts, and tasks, an ecosystem can be defined as the union of institutions restricted to services and service chains, typically involving several institutions. For example, the home dialysis ecosystem, which has the following initial structure:

$$hospital|_{dialysis} \cup homecare|_{dialysis} \cup transport|_{dialysis} \tag{9}$$

In order to enforce the notion of trust in computational ecosystems, it is not enough to just model the entities and the coordination of them according to the ORA modelor an institution restriction (as in Eq. 9). We must also address the notion of trust in terms of a supporting architecture and a supporting infrastructure in order to offer a basic structure and methodology for the modeling and implementation of entities in a computational ecosystem. The infrastructure consists of a number of primitive entities and system functions (corresponding to primitive institutions) that need to exist in order to enforce the purpose and goal of the ORA model and consequently also the implied architecture. In summary, we need both an architecture and an infrastructure in order to handle methodological issues of computational ecosystems.

5.1 Primitive Entities

From a system perspective, a computational ecosystem is constituted by a number of entities that fulfill the concepts outlined by the ORA model, i.e. ownership, responsibility, and accessibility. However, by fulfilling these concepts we have also implicitly stated that there have to exist some sort of primitive entity that connects the real world with the virtual world, i.e. the physical environment and the computational environment. This connection manifest itself as a person/organization representative. This type of primitive entity represents a physical individual in the computational ecosystem, and hence, if an individual has willingly introduced his/her representative into the system, the rules and norms of the ecosystem explicitly applies not only to the representative in the computational ecosystem but also to the individual/organization in the real environment (responsibility propagation). We denote such a primitive entity *owner*.

Another type of primitive entity that must exist in a computational ecosystem is a portal. As we have previously described, the ORA model defines accessibility as the basic means of communication and manifestation of entities in a computational ecosystem. The primary responsibility of a portal is to map the concepts of manifestation and communication into a direct access to an entity (the portal could just as well partly prohibit such access, offering a certain sense of high-level security). In other words, if one entity wishes to find another entity, this is done by posing a query to the computational ecosystem concerning a certain set of concepts. The result from such a query is a reference to some set of entities, that matches the specific set of concepts. The primitive entity in a computational ecosystem that is responsible for performing this specific task is called a *portal*. In summary, the primitive entities of a computational ecosystem strives to fulfill the complex mapping between two different aspects of the ORA model: world-to-world mapping and concept-to-entity mapping.

5.2 SOLACE: Computational Ecosystem Support

In terms of implementation, an embodiment of a concept must rely on a defined architecture, since the intent of an architecture is to support the modeling and deployment of entities that address the concept. However, an architecture does not by itself enforce the concept in question. This task must be achieved by the entities themselves. Therefore, we must introduce the notion of an infrastructure, i.e. a set of primitive entities that always exist in a computational ecosystem. Thus, in our case (considering the ORA model) these primitive entities must support the concepts of ownership, responsibility, and accessibility. Our suggested approach is called SOLACE (Service-Oriented Layered Architecture for Communicating Entities).

The architecture is divided into three logical layers on a functional basis: entity layer, proxy layer, and access layer. At the entity layer the two concepts of ownership and responsibilities are handled through entity behavior (e.g. providing services and handling of conditions and contracts). Each of the entities represented at the entity layer must in some way handle the requirement of accessibility and therefore each entity has a counterpart in the proxy layer. A proxy is responsible for the successful handling of the manifestation of an entity and its communication capabilities (i.e. accessibility). The third layer of the architecture, the access layer, very much corresponds to the three lowest layers of the ISO OSI model: link layer, network layer, and transport layer. In other words, the access layer of an ORA architecture can be viewed as the communication medium of a computational ecosystem.

As previously described, we can not handle the notion of trust in an effective manner if we do not include functions into an ecosystem that are normally only to be found in human societies (i.e. institutionalized power). As soon as an entity wishes to be part of an computational ecosystem it must register its existence. At registration of its presence in the ecosystem the entity must also supply the surrounding environment with a number of descriptive properties that outlines its manifestation. In SOLACE this is taken care of by portals. As previously

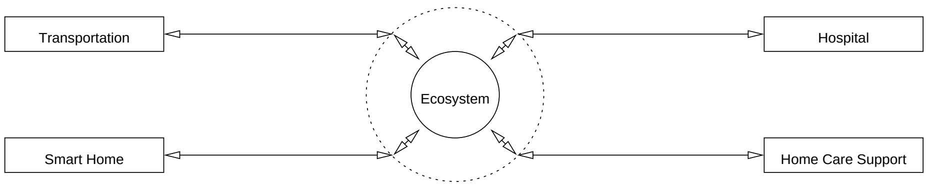

Fig. 1. Basic features of an electronic health care system: transportation, home care support, smart home, and hospital (cultural aspect of the system). The dotted area in this figure depicts an ORA mirror.

described, an entity must also be owned by someone, due to the fact that if there is no explicit ownership of an entity it is impossible to sign a contract between an entity and the user of an entity. The handling of entity ownerships in the infrastructure is also taken care of by the portals. And finally, every time a contract is signed between two entities, it must be registered for future reference, i.e. if a contractual agreement between the two parties for some reason is broken and one party wishes to take legal action, the validity of the contract has to be confirmed by a trusted third party. In SOLACE, this type of trusted third party is referred to as contract registries.

6 Designing a Computational Ecosystem

As previously described, an ecosystem can be viewed as a combination of a number of restricted institutions, emphasizing a certain task at hand (Eq. 9). In this design example, the emphasized task is home dialysis. Previously, the task of home dialysis was supposedly performed by one single institution (i.e. a hospital) and this institution had the sole responsibility for successfully conducting the task. However, for various reasons, we now want to make use of a number of different institutions that can aid in performing the task at hand (see Figure 1). All of these institutions have one thing in common, they are physically distributed at different locations, one of them is even mobile (i.e. transportation). The question now is: how do we design a computational ecosystem (virtual world) that reflects the home dialysis ecosystem in such a way that trust by all involved parties in the system is enforced? Our initial premises in designing the computational ecosystem are:

– *Value-Chain Consistency.* All tasks involve a number of services, supplied by a certain institution, forming value-chains. These value-chains must never be broken when the structure of an institution changes (e.g. as a result from distribution).
– *ORA Consistency.* All services involved in a value-chain must always be accessible, fulfill some responsibility, and have a clearly stated owner.

In the design process of a computational ecosystem it is important that we first identify the involved services. It is not until this activity of identification has been successfully performed that a number of tasks will reveal themselves as possible to conduct in a computational manner, hence, forming the basis of a computational ecosystem. The original institution (i.e. the hospital) supplied the care taker with a certain value-chain (i.e. dialysis), comprising the following services: monitoring, preparation, conclusion, and transportation.

The main idea at this point is that the original value-chain shall be distributed in such a way that the monitoring service can be physically located at the home of the care taker. Originally, the hospital had the complete responsibility of the value-chain in question, since all services where related to the context of that particular institution. However, if one of the chain's services is relocated into the context of another institution, how will this affect the responsibility of the original institution? We have to further analyze the involved services and see if they are possible to decompose, and then relate the decomposed parts with certain contexts. After this we will be able evaluate their accessibility and consequently also their ownership and responsibility.

The actual purpose of the monitoring service is to gather information concerning not only the care taker, but also the involved machinery. Furthermore, these monitoring sessions have to be constantly logged in order to deduce a knowledge base concerning both the care taker and the machinery. In other words, the monitoring service can be decomposed into three services: care taker monitoring, machinery monitoring, and session logging. When it comes to the preparation of a dialysis session, this service can also be decomposed: machinery setup, care taker calculations (e.g. "wet-weight"). Finally, the last two services (conclusion and transportation) can be considered as non-decomposable.

We have now decomposed the value-chain into a number of services, that previously were related to the context of the hospital. At this point we move the following services into the context of the smart home (since this is where the care taker will be situated from now on): machinery setup and care taker calculations. The reason for this is that they are services related to physical preparations of the session, and cannot be performed in a context other than that of the care taker location, i.e. the smart home.

Obviously, it is only the information processing services of the decomposed value-chain that can constitue the computational ecosystem of a dialysis session. These services are: care taker monitoring, machinery monitoring, and dialysis session logging. However, due to the fact that the services fulfill their responsibility over a spatial distance and that information processing in general is involved, a number of opportunities as well as difficulties arise. The opportunities arise since the services and the information they process can be used to produce new information, relevant not only for the hospital staff but also for the care taker and the smart home. Hence, new services can be introduced into the computational ecosystem that are of benefit to all parties involved. Furthermore, since the information processing services communicate over a spatial distance the dialysis sessions do not have to be conducted in the hospital, but rather in the context of the smart house. However, the difficulties of changing the role and responsibility of the original institution arise for the same reasons as the opportunities. Monitoring sessions have to ensure connectivity between the involved services as well as institutions involved in the value-chain. Furthermore, security, integrity, and privacy of information must be completely guaranteed.

In section 5 Computational Ecosystems, we identified the need for a primitive entity type in computational ecosystems called portal. Such an entity is supposed to handle concept-to-entity mapping on request from entities in the system. When it comes to our home health care ecosystem we need four different portals (one per institution): hospital, transportation, smart home, and home care support. Each of these portals will keep track of the entities/services related to that particular institution, and upon a certain request, a given service reference can be supplied to the querying party. However, it is important to notice that a portal does not necessarily only have to handle concept-to-entity mapping requests, but could just as well make use of this mechanism to ensure that requirements such as security, integrity, and privacy of information related to the services associated with a particular portal is effectively taken care of.

Associated with each portal, as with all entities in a computational ecosystem, is an owner. All of the owner entities are associated with a person/organization in the real world, and as previously stated, when a owner entity is introduced into the computational ecosystem all rules and norms apply to this entity as well as its associated person/organization in the real world. In the case of the health care ecosystem, we have a minimum of four owner entities, corresponding to the involved institutions. However, the number of owner entities could just as well correspond to the number of services involved in the complete ecosystem.

The final type of entities/services that are involved in our health care ecosystem are those that specifically correspond to the information processing services previously described in this section. All of these services can now be associated with their corresponding portal, ensuring proper handling of issues such as security and integrity. Furthermore, by introducing the services into the ecosystem, they must also be associated with a certain owner entity. In effect, if a service present in the computational ecosystem does not fulfill its responsibilities towards a certain person/organization, this can be traced back to that particular entity's owner, and consequently also its corresponding person/organization in the real world. We believe that this chain of responsibilities and ownerships can be used as a fundamental trust enforcing mechanism.

7 Discussion

Today, a great deal of effort is put into the area of trust, on issues regarding electronic commerce [3][5]. There reason for this is a need to create trust between consumers and on-line vendors. In other words, the vendors need to gain an acceptance from users, that in many cases do not trust the processes involved in the setting of electronic business. In this context, trust can be enforced by making use of various technologies, increasing peoples level of confidence in electronic commerce. However, the biggest barrier in achieving this confidence is a lack of trust from the users' perspective in how on-line vendors handle private customer information. Typically, the consumers fear that their personal information is sold to other companies or used for unwanted purposes. If private information is sold to a third party, this can cause serious damage concerning the notion of trust involved. There may not be any clearly stated rules and norms for this kind of system failures, but there are ongoing investigations[1].

Similar issues on information integrity and security are important also in health care. For instance, privacy requirements concerning patient records must be considered fundamentally important in the development of systems aiming at this type of businesses. In the setting of home dialysis the consequences of unexpected entity behaviour or system failures may affect peoples health, quality of life or in a worst-case scenario, cause the death of a patient. Hence, trust in computational ecosystems (e.g. home dialysis) needs to be treated in a completely different way than today. In order to enforce trust in a home dialysis ecosystem, a number of additional functions may need to be supported and properly handled. Below we present a selection of functions (supplied by the various institutions) in a home dialysis ecosystem:

At the Home of the Care Taker

- *Automatic Sampling of Vital Measurements.* One of the most serious incidents that could occur during a dialysis session is that of a sudden drop of blood pressure.
- *System Feedback.* Dialysis equipment in hospitals are designed in order to be monitored by professional nurses, who can read different values and combine them in a way that make sense for involved personnel. The patients neither can nor are allowed to fully control and/or manage the dialysis equipment. With this in mind, a system where the patients themselves are actively participating in the dialysis session have to be designed in so that the patients receive proper system feedback.

At the Hospital

- *Responsibility.* Since a dialysis session is associated with risks, the involved care takers need to undergo capability assessments, ensuring their right to earn certain responsibilities.
- *Regular Contacts.* Regular contacts with the home care unit and the care taker. A home dialysis ecosystem makes it necessary to increase the frequency of contact between the hospital and home care unit, in order to receive feedback concerning the home environment of the patient.

[1] See www.privacy.net about lawsuits filed towards banner advertising companies

Home Care Unit

- *Service Credibility.* The home care unit must verify the credibility of hospital services offered to a patient situated in his or her own home, and that the patient is able to operate the service in question. Otherwise they may not be able to acknowledge their responsibility in the value-chain.
- *Frequent Contacts.* Frequent contact with the care taker is necessary for the home care unit, in order to understand how the care taker understands and uses a certain service. This is also important in order to ensure the quality of service.

Some of the functions above may be accomplished using a computational ecosystem, but several of them relate to tasks and solutions of a non-technical nature. For instance, the care taker will still need to visit the hospital on a regular basis, even if some tasks may be possible to perform at a location other than that of the hospital. In order to provide a service, the supplying institution must be able to trust the subcomponents (entities) of the system. If this is not the case, it will be very difficult (if not impossible) to construct and develop services supporting the ORA model.

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