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Steps towards a digital health ecosystem

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ABSTRACT

In the paper an IT infrastructure for supporting the shift from organization-centric to patient-centric model of healthcare service delivery to facilitate collaborative, multidisciplinary and cross-organizational healthcare delivery processes is presented. The core of this infrastructure is an internet platform that provides e-services and promotes the interoperability by enabling not only inter-communication among authorized healthcare professionals, but also sharing the Virtual Healthcare Record, an authoritative, multi-dimensional view on the patient health state.

The platform is implemented in the LuMiR project for Basilicata, an Italian region where integration of healthcare applications is required. The LUMIR approach, its origin and peculiarities are briefly presented. The project's final target is the regional health digital ecosystem that interacts with the healthcare system for better supporting it. The agent-oriented paradigm emerges as a promising approach to map the autonomic healthcare systems and their users in virtual entities, and to add values such as flexibility, adaptability, and reusability. over traditional object- or service-oriented approaches.

1. Introduction

Recent trends in healthcare service delivery promote integrated and patient-centric care provided by multidisciplinary teams and multiple care delivery settings along the continuum of a disease. To place the patient at the center of care means also to focus on prevention and wellness, and to attend to the physical, mental and spiritual needs of the citizen. The existent healthcare systems are not suitable to meet these requests because they are oriented to acute disease care, emphasize short encounters of patients with their caregivers where the healthcare professionals are the main actors, favor diagnosis and treatment of current symptoms, and usually support the caregiver's activity in solitude. Healthcare systems are still largely paper based, ignore information tools that can facilitate evidence-based best practices, and function without analytics to qualify and quantify the care they provide. Medical decisions are made according to implicit criteria embedded in the physician's reasoning and knowledge rather than explicit criteria, that is external knowledge that can be checked, evaluated and updated.

To face such a challenge as the shift of the health paradigm a systematic adoption of healthcare Information Technologies (IT) is considered a necessity, not only an opportunity. With the IT support management of chronic pathologies, home recovery, patient empowerment and coordination of clinical pathways with multiple actors are possible. IT adoption allows to innovate or re-engineer healthcare sectors to promote the economic sustainability of healthcare services and improve their quality. The healthcare IT is also the instrument that will transform healthcare to combat the unsustainable cost curve. For this, applications, processes and work flows that will improve quality, safety, access and cost efficiency are needed.

In European Union, where patient and health care provider mobility is increasing, finding the same standard of healthcare is addressed by the goal to create a European eHealth Area, facilitating the interoperability between healthcare organizations. In 2004 the Commission adopted the eHealth action plan [1] covering everything from electronic prescriptions and health cards to new information systems and calling on Member States to develop tailored national and regional eHealth strategies to respond to their own needs. Fostering electronic health record (EHR) systems has been among the earliest research topics of the eHealth strand of the European Commission's Research and Development Framework Programmes. This continuous commitment has started to pay off as various eHealth solutions are being adopted on an increasing scale.

Abbreviations: EHR, electronic health record; DHE, digital health ecosystem; FSE, Fascicolo Sanitario Elettronico, namely Electronic Health Folder; LUMIR, Lucania – Medici in Rete, namely Lucania – Networked Physicians; MAS, multi-agent system; VHR, Virtual Healthcare Record.

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England's National Health Service (NHS) National Programme for IT aims to transition NHS in England towards a single, centrally-mandated electronic care record for patients and to connect 30,000 general practitioners to 300 hospitals, providing secure and audited access to these records by authorized health professionals. The program aims to create this national healthcare infrastructure in a number of deliverables among which we have the Care Records Service, containing different types of care records: summary care records (held nationally), records held in prescriptions and detailed care records (held locally) [2] .

In Sweden the efforts in introducing eHealth are reunited in a National Strategy for eHealth [3] in which the patient record system called Swedish National Patient Summary is being deployed starting from 2009. It is the first national EHR for Sweden, and is billed as one of the first of its kind in the world.

Ref. [4] enumerates some other working EHR systems:

- Computerized patient record systems at the University Hospitals of the Canton of Geneva, Switzerland
- Regional EHR and ePrescribing System Diraya in Andalucía, Spain
- The Kolín–Čáslav health data and exchange network, Czech Republic
- Dossier Patient Partagé Réparti (DPPR) – Shared and Distributed Patient Record platform in the Rhone–Alpes Region, France.

LUMIR is an Italian IT solution that supports the shift from organization-centric to patient-centric model of health service delivery in Basilicata, a small, mountainous region of 600,000 residents in the southern Italy. This infrastructure will provide e-services that facilitate the interoperability among authorized healthcare professionals by enabling the communication and sharing of patient-related multi-dimensional data in order to promote collaborative, multidisciplinary and cross-organizational healthcare delivery processes. LUMIR is conceived to be the core of the Regional Integrated Health Information System scheduled for 2014.

In the following section the LUMIR project with its origin, inception, and the system context and requirements is introduced. Main design issues for the infrastructure development: interoperability, the service platform, integrated environment, and implementing technology, as well as the solutions we adopted for them are presented in Section 3. In Section 4, the LUMIR system evolution towards LUMIR 1, the current version of the system, is presented. A representative scenario for working with LUMIR1 is included. Stepping from component-based LUMIR 1 version to the multi-agent-based LUMIR 2 version is presented in Section 5. In this section is argued why we chose the health digital ecosystem paradigm to model the overall digital environment where local health applications have to be connected in order to communicate and collaborate with each other. Special emphasis is given to the multi-agent system architecture that should implement the digital health ecosystem. Issues as agent identification and agent organization in the digital ecosystem are also discussed. Expected impact and change, and conclusions are presented in the final sections.

2. The problem

2.1. The healthcare system in the Basilicata region

The regional health system in Basilicata is organized in five jurisdictional areas: two Provincial Health Authorities, which are entitled of managing and carrying out the delivery of healthcare services for all citizens in the province (they employ provincial hospitals, ambulatories and laboratories), two autonomous hospitals: one for secondary and tertiary care and the other for research and care in oncology, and the Regional Health Authority which governs and manages the regional health system by controlling and monitoring it, financing projects, and reporting global indicators and data to the national government.

Diffusion of IT in the healthcare system and the level of automation in healthcare activities in Basilicata are not uniform over the Region's territory. The deployed software (legacy) applications include:

(i) specialized applications in hospital departments and/or ambulatories; they are partially integrated in organization-wide information systems in only few hospitals in the region;
(ii) several EMRs for GPs and pediatricians offices, and
(iii) regional applications: the registry of welfare beneficiaries, the registry of caregivers, the regional booking system for outpatient services, the networked service for the management of first aid/hospital admission, discharge and transfer, and few others.

In this heterogeneous context, the LUMIR system intends to promote the diffusion of eHealth all over the region, accelerating the modernization process in all points of care, stimulating innovation or reengineering of healthcare-related business processes, and the development of novel services for professionals and citizens. According to the Integrated Health Information System's vision, in the long term all the public points of care in the Region will be interlinked together via the LUMIR system and all the citizens will be able to freely access the information on their own health status, according to national and regional privacy laws and regulations. Other business activities which will indirectly benefit of the LUMIR system are those related with the secondary use of de-identified and aggregated clinical data and information (e.g. management and governance of healthcare organization, epidemiology studies, biomedical and healthcare research, etc.).

Fig. 1 introduces the context where the LUMIR platform evolves and gives a hint of how the LUMIR platform integrates all health applications and information systems. This context is also the all-encompassing environment where business scenarios (e.g. patient care, governance or prevention) are carried out.

2.2. LUMIR inception

The LUMIR project began as the enactment in Basilicata of the "General Practitioners' Network" program whose Italian abbreviation is RMMG (Rete dei Medici di Medicina Generale). The program was launched by TSE (Tavolo di Sanità Elettronica, namely Permanent National Board for eHealth). According to European directives and national roadmaps, the TSE established to carry out a national strategy for eHealth [5,6] in order to:

- harmonize the eHealth initiatives individually promoted by the 20 Italian regional governments, and
- support a coordinated implementation of a cross-regional interoperable IT infrastructure for health.

TSE launched innovative regional pilot projects with high commonality and reusability of solutions aiming to build communities of practice with different levels of specialization. RMMG was one of this suite of projects.

RMMG aimed to foster the implementation and adoption of interoperable regional software infrastructures in Italian regions in order to stimulate and support the collaboration between general practitioners (GPs), pediatricians, and other healthcare professionals, across healthcare teams and settings, in the delivery of IT-enhanced integrated healthcare services. To this aim, the TSE

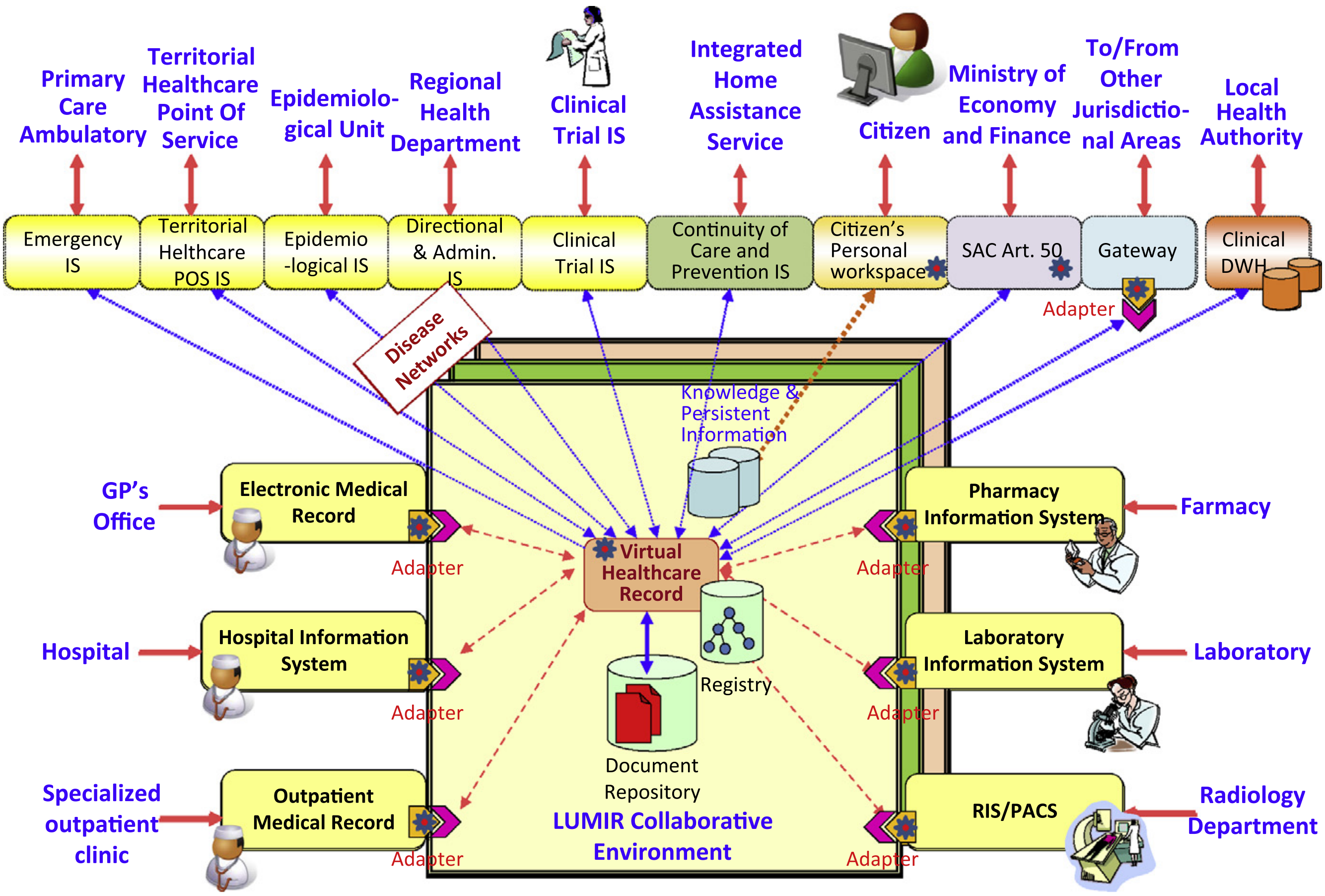

Fig. 1. LUMIR and its environment.

issued a high level conceptual framework as well as an architectural specification for a software infrastructure called IBSE (Infrastruttura di Base per la Sanità Elettronica, namely the eHealth Basic Infrastructure) for indexing and routing clinical documents. The core of this infrastructure was called FSE (Fascicolo Sanitario Elettronico, namely Electronic Healthcare Folder) that gathers clinical documents as they are generated.

The IBSE platform has a federated, registry/repository-based, service-oriented architecture (SOA). It was conceived as a completely decentralized platform where jurisdictional areas in the national health system (main hospitals, and Provincial and Regional Health Authorities) provide needed processing and network resources. These areas are represented as nodes in a nationwide peer-to-peer network that enables cooperation among the Italian Public Administrations even if, for a user, the infrastructure should appear like a sole system. To this aim enabling federation of local resources, metadata registries and document repositories, was a meaningful design decision of the TSE.

Registry federation is obtained with an event notification mechanism: every time the metadata of a new clinical document is stored or the metadata of an existing document is changed in a registry, the new metadata is notified to all local registries that had previously subscribed for receiving such an event.

To achieve the interoperability objective syntactic and semantics aspects were considered:

- Structured documents: prescriptions, laboratory reports, patient summaries, emergency data set and so on were codified as HL7-CDA Rel.2 documents.
- Shared codesystems for clinical and administrative uses were promoted

To communicate with other jurisdictional areas a jurisdictional area employs a nationwide SOA platform, referred to as SPCoop (Sistema Pubblico di Cooperazione, namely Public Cooperative System), a framework that implements the normative specifications for the (web service based) cooperation among the Italian Public Administrations [7]. As a technical and organizational platform, SPCoop aims to create the conditions for a long-lived legally valid cooperation among administrations. It is based on formalization, and successive publication, of service agreements between Public Administrations, a definition of a federated identity management system for access control, and a definition of the metadata about the effective data to be used for cooperating, as well as of the semantics and of domains' ontologies.

Even if it was maintained that the FSE is the equivalent of the longitudinal EHR, the IBSE architectural strategy is based on a "document-centric" approach where only electronically signed documents are expected to be exchanged, stored and discovered within the IBSE infrastructure.

2.3. Targeting LUMIR

From the beginning of the LUMIR project a framework of collaboration between care providers that is based exclusively on document sharing, as the TSE guidelines and technical specifications appeared to us too restrictive. There are mainly two reasons to discard the idea to implement a document-oriented EHR:

1. To answer complex and longitudinal user-requests as, for instance, in the synthetic grouping or charting of some biological parameters, a set of documents as many longitudinal EHRs offer, can reveal hard to be processed. For these kinds of user-request it is preferable to manage smaller, but meaningful chunks of content or atomic structured data and aggregate them according to pre-defined or on-demand forms.
2. We consider the generation of a new clinical document as an event of secondary importance, a simple service on behalf of another, more relevant one, that originated the document. Our approach is centered on clinical events representing significant changes in the citizen's health status. The significance of such an event is assessed only during an encounter or contact the citizen has with a health practitioner. During the contact one or more clinical documents can be generated. They assess the professional services that the caregiver carried out in order to restore or improve citizen's health status. The content of the generated clinical document explains the clinical decisions of the caregivers only in the context of the contact. Only in this context the document is relevant for clinical purposes.

This is why rather than handling only entire documents we decided to extract the clinical information from the clinical document and include it in the contact information. In this way, the contact event has two kinds of associated information: a where-when-who-why context description and the payload of non-redundant information on delivered professional services that is contained in the clinical documents issued during the contact.

As a consequence the IBSE infrastructure is implemented in LUMIR as a document service that archives released clinical documents and preserves document-based interoperability with other Italian regions.

The patient-centric paradigm and the integrative vocation of the LUMIR system demand an inclusive collaboration of all caregivers and their organizations during the whole life period for any citizen in Basilicata. This is why the project progressively evolved in two directions:

- all business use cases were revised in order to better correspond to the medical practice especially that evidence-based, and
- the LUMIR objective was extended from a document-based infrastructure towards a clinical event-based infrastructure of the regional integrated health information system.

As a consequence, the functionalities of the LUMIR platform were extended to enable it to:

- integrate all (new and existent) healthcare systems/applications in the Region in order to support collaboration with each other, and
- support all various business processes in the regional health system ranging from patient care provision to health governance, in particularly continuity of care, epidemiology, prevention, citizens' health portal, etc., with coordination, control, alert, and monitoring services.

All business scenarios evolving in the environment presented in Fig. 1 are based on a publish-subscribe pattern: a peripheral health application or information system publishes a clinical event and notifications on this event are dispatched to all applications and information systems that are interested in the event. Contemporarily, the clinical event message is analyzed and interpreted by the LUMIR platform, and all relevant information contained in the message is integrated with the already existing one.

This extension induced us to analyze integration and interoperability aspects and interrogate on the best business and software architectural solutions to sustain such a support, Moreover seamlessly integration of new and legacy applications, promotion of reusability, extendibility, easy adaptability to changes in the environment, and assurance of information security and privacy by policy-based configurable models were also considered.

In the following section the major design decisions and their rationale are presented.

3. Methods employed

General health-oriented functionality principles deriving from the necessity to support integrated and patient-centric care in the health system of the Basilicata region guided us to take important business and software architectural decisions important architectural decisions are enumerated in the following sections.

3.1. Semantic interoperability

In the environment of a health service information is generated and interpreted in the context of purposeful conversations in relationships of care. By this we mean people with roles, responsibilities and relationships interacting and transacting in order to perform their roles and discharge their responsibilities. The result is a complex web of conversations which take place over space and time and generate units of information that can have different meanings and significances in different contexts. The same items or sets of information may serve different clinical, management, governance or research purposes.

On the other hand, due to the great heterogeneity of the health applications, their large scale integration imposes interoperability to be a central topic in our project. The messages exchanged by health applications should contain all the sufficient and necessary information the receiver should possess to correctly interpret the intentions of its interlocutor and for a given message both partners must agree upon each other's behaviors. This should happen even if the message content is a behavior description itself. In fact, during a healthcare process execution the activity flow between care providers and consumers, and health care settings is coordinated by some known, well-established rules, usually represented as a workflow. The workflow execution has to be as efficient as possible, but not statically settled: proactive improvements must be supported, because the patient-centric paradigm does not imply an immutable set of guidelines, rather a fluid and still-evolving workflow definition according to practices that benefit patients. Moreover, redundant, useless, or unwanted services for the current workflow instantiation should be notified and removed from the enacted business processes. As a consequence, descriptions of some behavior could be encapsulated in messages and sent to other applications for triggering there the behavior that the sender expects. Business process descriptions for the main scenarios in the health system have to be explicitly available and so must be policies to be applied in well-defined situations. Information must follow the activity flow seamlessly, enclosed in interoperable messages. All these are possible only if domain- and process-oriented ontologies are available to be used by applications in the integrated environment.

To obtain interoperability we decided to create a "LUMIR-standard" space where communications between various healthcare applications happen in a uniform, message-based style. With such messages the care providers inform the community of other care providers about changes in the health status of a patient, the decisions they have taken, and the corresponding delivered healthcare services.

The message content has to be understood by all applications in the collaborative environment. For this, the applications should share a unique conceptual model. A comparative analysis of standards like HL7, CEN, SNOMED CT was employed to define a conceptual core for the LUMIR domain model.

To guarantee semantic interoperability the messages sent or received by local applications across the LUMIR system have to contain only descriptions of concepts in the LUMIR conceptual model that all local applications have to interpret in the same manner.

We expect to have a lot of message types originating from local applications and directed to the LUMIR platform. They reflect the great variety of concerns and intentions the various stakeholders of the system have regarding the services that LUMIR should provide. Identification of new message types is in progress, others will be identified in successive steps. To maintain the message list open we decided to embed all the message types in a unique one, the so called M1 message, and distinguish them according to the generic "intentionality" of the external events they represent: information, command, control, query, etc. Each M1 type has its own structure and subtypes.

To exemplify this approach, let us consider the use case of a patient's encounter with her/his caregiver. Information on such encounters is encapsulated in a M1 message and sent to the LUMIR platform. The UML class diagram in Fig. 2 gives a hint of concepts that this use case employs. The diagram is a partial view of the LUMIR conceptual domain and is centered on the Contact and Episode of Care concepts. These concepts originating in the clinical practice are used in the LUMIR space to classify and structure patient related information into messages.

A *Contact* represents an encounter of a patient with a healthcare professional or organization in relation with a possible, worrying change in the patient's healthcare status. During the contact a set of documented healthcare services is provided to the patient: observations, diagnosis, therapy, treatment, and medication. Information about these services is captured by the caregiver's application in clinical documents that are attached to a M1 message according to the InsertContact structure of the M1 message representing a new contact event. General information on the new contact includes: responsible caregiver, health organization, description, goal, provided service list, effective time, etc. In our approach, only digitally-signed, HL7-CDA r2-compliant clinical documents [8] may be attached to a message concerning a contact. These documents describe the healthcare services the care provider carried out during the encounter with her/his patient. According to the information relevance the caregiver has to decide if the message should be sent to the LUMIR platform or not. After the message is sent to the LUMIR platform its contained information is integrated with already existing information on the patient's healthcare status.

There are other M1 message structures for contact management. For an existing contact AddDocument adds new documents to, ModifyContact Attribute changes attributes and ModifyContactState changes the state of the contact.

An *Episode of Care* is a sequence of chronologically ordered contacts that correlate with a particular health issue or worrying health situation. It initiates with a triggering contact that assesses a change in the patient's healthcare status and continues with other contacts until the health problem resolution is obtained. An episode of care has several attributes: author (the caregiver that created the episode), description, associated health issue, and state: open or closed. It can be seen as a logical folder where any caregiver can add new contacts to the episode, but only the episode author can modify its attributes. The episodes of care may be overlapped. All changes in episodes or contacts are persistently recorded. In this way evolution of medical diagnosis as well as collaboration of caregivers during an episode of care can be traced.

The core of the LUMIR domain model also contains other essential concepts like as: HealthState, HealthCondition, Clinical Observation, Diagnosis, Clinical Pathway, and Treatment Plan [9,10]. All these concepts represent the semantic basis for message exchange with the LUMIR infrastructure according to the following basic scenario:

1. a caregiver having her/his local application connected at the collaborative environment notifies everybody who is interested that a significant change in her/him patient's health status occurred.
2. LUMIR analyses the message metadata, creates a notification dispatching message called M2 and sends it to all local applications that previously subscribed for receiving notifications of this type.

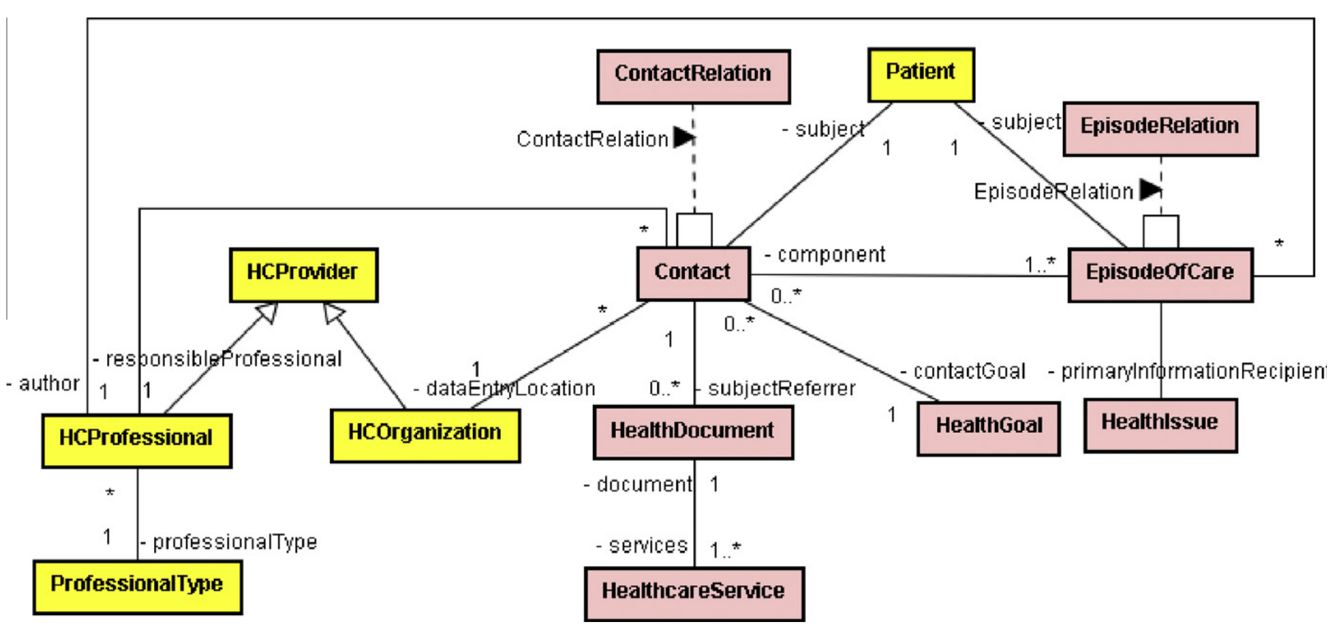

Fig. 2. Partial view of the LUMIR domain model.

According to the HL7 v3 methodology [11] for obtaining message structures that describe clinical events by using concepts in the domain model, we first derived the LUMIR Domain Message Information Model (DMIM) from our model, then the Refined Message Information Model (RMIM) is obtained from DMIM and finally the corresponding HL7 v3 message XML specifications (HMD) are obtained from RMIM [9].

Fig. 3 presents the structure of a M1 message. The header part contains all metadata that the LUMIR platform uses for dispatching and integrating the information on the clinical event contained in the message. The body part has a big choice tag that selects one of the possible alternatives for a M1 message: InsertContact, ModifyContactState, InsertEpisode, ModifyEpisodeAttribute, etc.

3.2. Implementing the Virtual Healthcare Record

We consider that a true collaboration among numerous care providers, citizens, and administrative staff dispersed over a wide area like a region or country requires a shared, virtually centralized, longitudinal patient record. This record should appear in its environment as a service providing entity that gathers data from the environment, integrates the gathered data in a consistent way, notifies any integration events, triggers and monitors executions of process instances, extracts compositions of the integrated data, and presents this data in various formats. We called this entity – a mix of highly structured data and process-based services – the citizen's Virtual Healthcare Record (VHR).

In our approach the VHR is a complete and authoritative representation of the patient's current health state, clinical history and ongoing care processes. Using VHR any stakeholder can obtain the data she/he needs: a physician can look up coverage information during the patient's care pathway and concentrate on fine-tuning the rules of the treatment plan, a manager in institutional health care settings can view daily charges of medication, a demographic analyst can complete his/her study of morbidity regarding the incidence and prevalence of sickness in the population during a certain reference period, or a patient can view the trend of her/his blood analysis in the last months, be warned of failures in taking the prescribed drug, and notify adverse events after drug administration.

VHR has to deal with two major goals:

a. providing services for information exchange with health applications in its environment, and
b. maintaining the coherency and consistence of internal information in order to (1) provide in any moment both an accurate and coherent "snapshot" of the patient's current health status and the history of her/his clinical events, and (2) monitor the ongoing care processes.

3.3. VHR architecture

VHR captures information generated during the citizen's encounters with care givers or medical devices in their care delivery settings. This information includes patient demographics, immunizations, progress notes, diagnostics, medications, values of vital signs, raw or interpreted laboratory data, radiology reports, past medical history, and treatment plans. VHR is more than a clinical repository because it also includes scheduling, billing, coverage and demographic data that are needed to better place the citizen and her/his clinical data in their appropriate context. The VHR information is structured by contacts, episodes of care, health issues, caregivers, medical devices and equipment, organizations, personal and territorial jurisdictions, and, of course, event occurrence and registration dates.

As Fig. 4 suggests, information in the VHR originates in clinical documents and in some other non-clinical documents but which are closely related to clinical events that physicians, other authoritative individuals or organizations working in healthcare generate on behalf of citizens' health status. For each citizen information in the VHR is structured in three areas: past medical history, current health status, and treatments in progress:

1. *The past medical history* is a collection of episodes of care that were triggered by health issues occurred in the past. Each episode is composed of a series of encounters of the citizen with caregivers and/or health organizations. Information about medical services that are provided during a contact for certifying, maintaining, or restoring the citizen's health is captured and integrated in the citizen's VHR.
2. *The current health status* is a composite information that describes the state of affairs of the citizen's health as subjectively assessed by the most recent objective measures or physicians' subjective, but authoritative evaluations that are usually embedded in diagnosis or patient summary documents.
3. *The ongoing treatments* are represented as *care plans*, that are customized, integrated clinical pathways which are able to manage the care process quality using evidence-based practice and the standardization of care processes. We chose to use care plans for treatment modeling because they better optimize outcomes in both acute care and homecare settings. Moreover, any physician who treats a patient by using a care plan can create, prescribe and successively develop it. She/he can also decide to share it with other caregivers and/or give them the possibility of customizing it. In such a care plan the different activities of the professionals involved in the patient care can be defined, optimized and sequenced.

With such an architecture VHR is able to answer complex queries related to the citizens' health status or clinical history, accommodate any multi-criteria decision-support logic for adhesion to evidence-based best practices, or evaluate and incorporate any authoritative assertion concerning changes of the citizens' health status.

3.3.1. User-oriented functionality

For each end-user, according to her/his role (care consumer or provider) and credentials, the VHR has the ability to:

- generate a comprehensive map of indicators of the patient's current health status;
- generate health summaries, that is problem/concern-oriented or query-or-rule-originated views within a patient's current health status. Such a summary involves processing of the health status in order to emphasize some aspects, those that are most important from a certain point of view, and reduces the complexity of the overall health status report. Processing includes filtering out unimportant detail or personal sensitive information, and/or re-organizing the information. The summary returned by a query may be stored in a persistent manner;
- generate for each episode of care a complete record of a patient's clinical encounters, and, for each encounter, a list of care-related activities or services including their outcomes;
- provide different 'views' of the data contained in it depending upon the desired context and wishes of the viewing agent;
- automate and streamline the clinicians' workflows in their comprehensive healthcare process that was triggered by the current episode of care.

VHR also provides services for evidence-based decision support, quality management, and outcomes reporting.

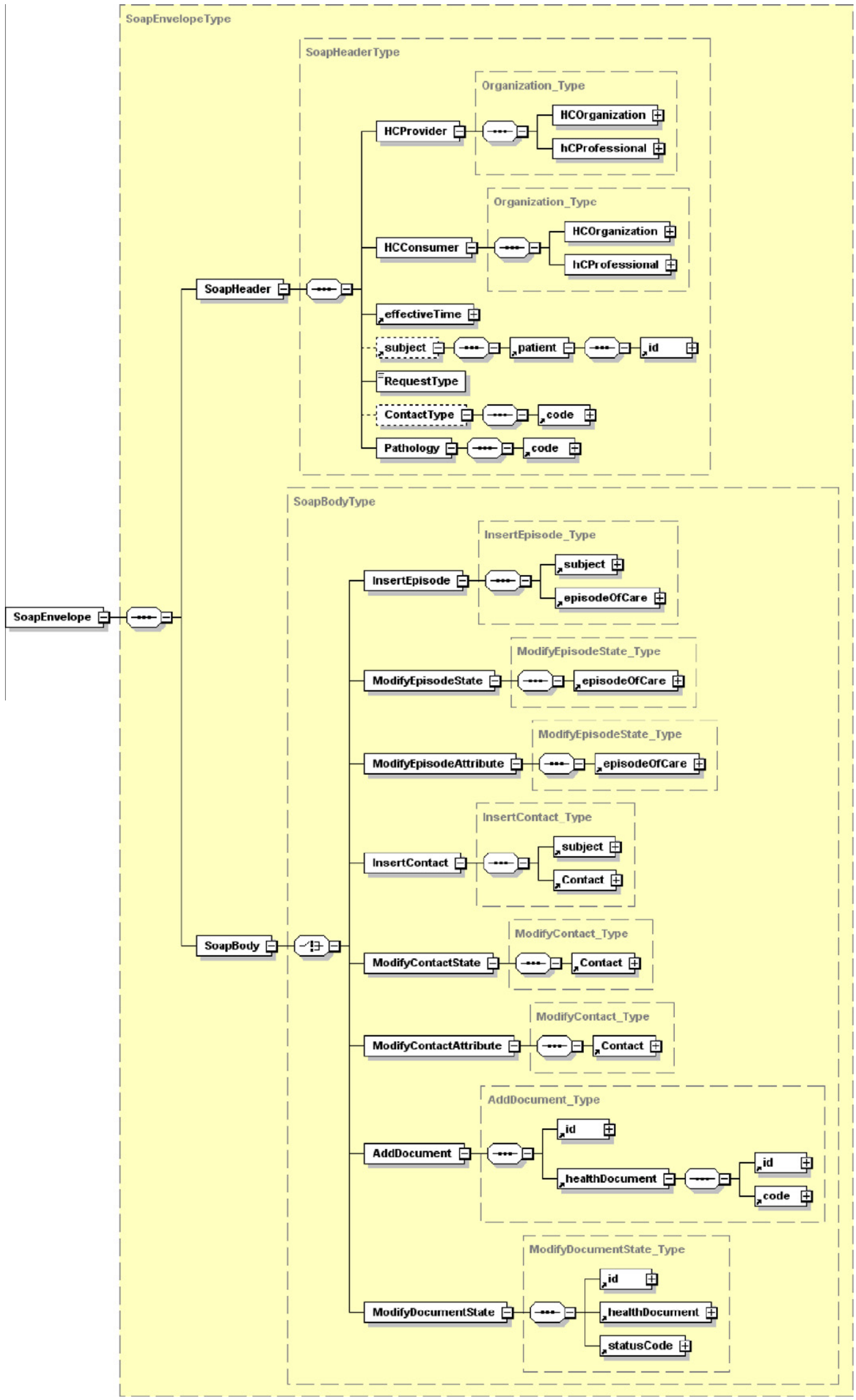

Fig. 3. The structure of the M1 message.

Moreover, with its proactive behavior VHR provides more than a consistent, comprehensive source of data, but also a trusted partner for the participants in the collaborative environment, who jointly support integrated and patient-centric care processes. The VHR can support the workflow of caregivers as well as evidence-based decisions, quality management, and outcomes reporting.

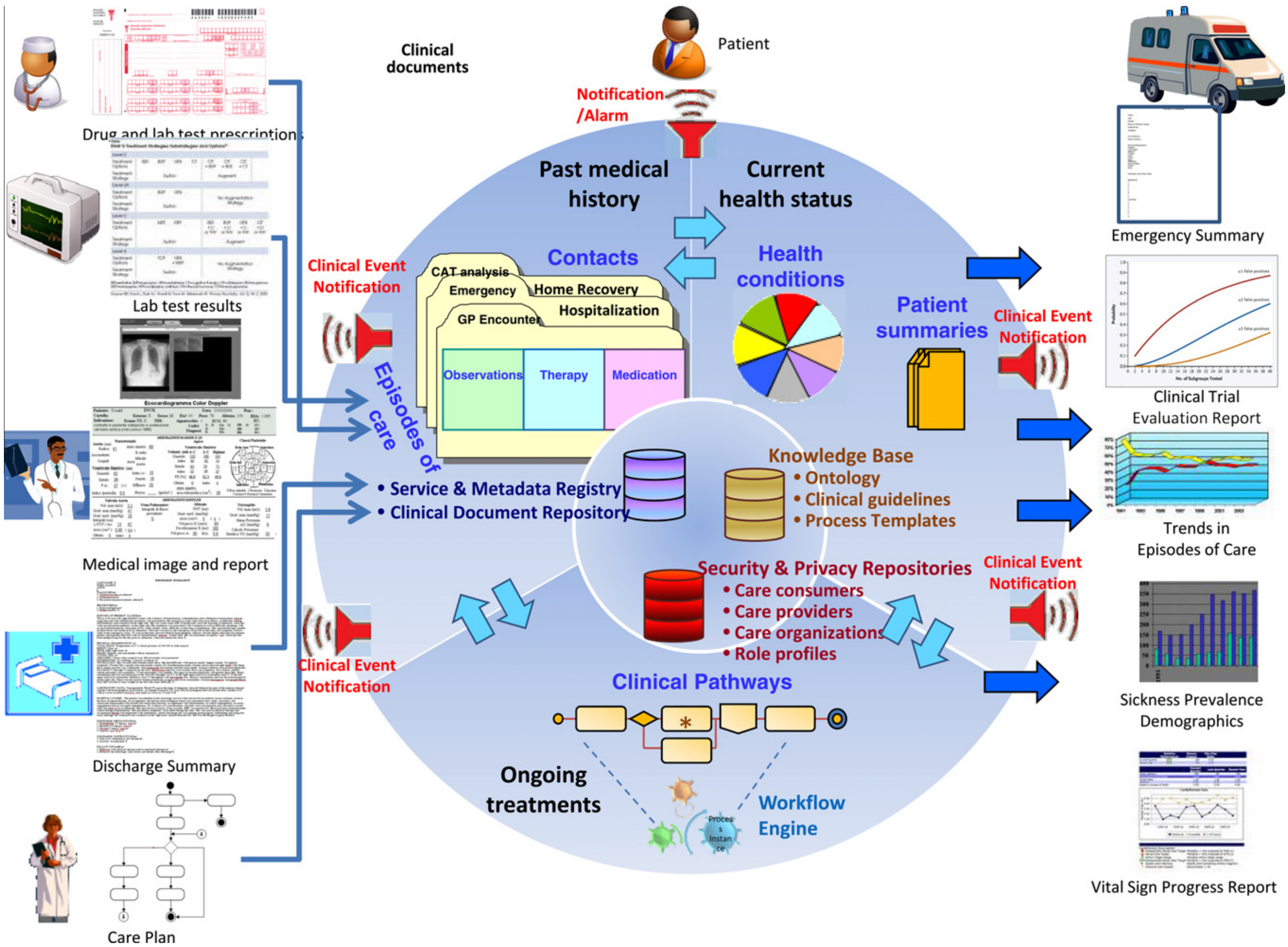

Fig. 4. The Virtual Healthcare Record.

VHR can be a valuable interlocutor for clinical trial information systems, too. The last but not the least, it can be the main information source for the patient's healthcare record (PHR) that we want to implement as soon as possible.

3.4. Supporting a digital health ecosystem

A natural life ecosystem is defined as a biological community of interacting organisms or agents plus their physical environment. Applying this definition to the health domain we can define a *health ecosystem* as the network of a multitude of agents: care providers (physicians, nurses, pharmacists, and other health professionals), health suppliers, together with their organizations and information systems, care consumers, plus the socio-economic environment and including the health institutional and regulatory framework.

The digital ecosystem approach transposes the concepts of a given natural domain to the digital world, reproducing some of the mechanisms of natural ecosystems [12]. It is a self-organizing digital infrastructure aimed at creating a digital environment for networked organizations that supports the cooperation, the knowledge sharing, the development of open and adaptive technologies and evolutionary business models. Such a digital ecosystem is populated by "digital components" which evolve and adapt to local conditions thanks to the re-combination and evolution.

In our approach a region-wide integrated health information system can be structured as a regional digital health ecosystem (DHE) [13] that exhibits many characteristics of the regional health ecosystem. It is composed from a network of local, hierarchical organized, digital ecosystems that preserve their identity and knowledge but will be also able to interact with each other in a global, digital cooperation among health organizations and user communities.

In the case of the Basilicata regional health system care providers and consumers, health care settings, and health organizations and departments in Basilicata are agents in the system. They and their health applications have to be effectively represented as software components in the integrated health information system. Such a component should incorporate as roles and role profiles, properties and behavior of the entity it represents. Let call these software components *virtual entities*. Furthermore an environment, let call it the *LUMIR digital ecosystem*, where the virtual entities may evolve and communicate must be created and managed by the LUMIR infrastructure. It is coupled and co-evolves with the regional health ecosystem. Any virtual entity in the LUMIR digital ecosystem plays a dual role: it has to be able to inform other virtual entities of occurrences of significant events in the application or for the party (person or organization) it represents, but it has also to inform the application or party it represents about event notifications received from other virtual entities in the environment. The virtual components are autonomous and communicate with each other asynchronously.

3.5. Implementing a DHE as a multi-agent system

We used the digital ecosystem paradigm to model our healthcare system more accurately, for properly capturing the processes, stakeholders and organizations in the real world. This model is mainly business-oriented and independent of implementation. The next step in developing our software system is to choose a software architectural style which supports the described business functions.

Software agents are software components that act autonomously across distributed environments to meet their design objectives, usually established on behalf of their users. The paradigm of agent-based systems technology can be used to specify, design, and implement software systems.

Applying the agent-based paradigm to complex health applications may require multiple agents that work together for solving problems in a multi-agent system (MAS) on behalf of organizations, professionals, care consumers, or even agents themselves [14]. We choose a multi-agent architecture for our ecosystem implementation as we find that it is the most suitable to maintain the expressivity of the model, together with the intrinsic heterogeneity and peer-to-peer relations.

We consider that the use of the MAS paradigm for implementing a DHE has the following important advantages over a traditional approach [15]:

1. the agent-based paradigm is a more natural way of representing many recurrently occurring situations in medical environments, as for instance: absence of a global system control, bounded or insufficient resources of a caregiver to solve a given problem, and knowledge and data distribution. Conversely, in the health systems we can identify many recurrent aspects common to the multi-agent systems: responsibility delegation, task re-allocation, taking in consideration of a great variety of user concerns, planning of the collaborative work, reasoning and working in open spaces, and so on;
2. the network of interconnecting agents better models the distribution and decentralization of computational resources and capabilities existent in the final health digital ecosystem. The system can better scale and do not suffer from the "single point of failure" problem;
3. a community of inter-related agents can coordinate and efficiently carry out operations of retrieve, analyze and integrate information from sources geographically distributed. It provides solutions in situations where knowledge or information is spatially and temporally distributed, for instance when it resides in documents stored in repositories of other regions or organizations;
4. interconnection and interoperation of existing legacy systems is enabled by the agent approach;
5. agents enforce interoperability, a fundamental aspect in large-scale, enterprise-wide integration. The HL7 v3-like messages M1 and M2 we use in the LUMIR space are examples of a "lingua franca" used to communicate between components not sharing the same native language. M1 and M2, the HL7 interoperable message that LUMIR boundary applications use to communicate clinical events to the platform's core agents, are entirely based on concepts from the LUMIR ontology. In the same way semantics for the inter-agents communication language should be founded on a LUMIR ontology;
6. "shifting to MAS" can add supplementary values over traditional object- or service-orientation regarding reusability, reliability, robustness, maintainability and adaptability.

Virtual organizations could be created and managed by specialized agents according the indications in the care plans. These agents create, and coordinate instances of the care plan-based-processes that monitor treatments and follow up processes in the real world. As a treatment proceeds, clinical information on events that occurred during its execution is automatically integrated in the VHR.

In the following sections the current state of the LUMIR system and future steps in the LUMIR project are presented.

4. The project's current state

Due to its complexity and being constrained of many institutional, organizational and technological issues, the development of the LUMIR system was based on an incremental life cycle model. Actually three main incremental releases of the LUMIR software infrastructure were scheduled: LUMIR p0, LUMIR 1 and LUMIR 2 [9]. The first two are briefly described in the followings. For the last we dedicate a special section.

A prototype p0 implementing the core functionalities was rapidly developed and early available. It was used to better elicit the LUMIR system requirements with the direct involvement of the end-users following a socio-technical approach. It was innovative because it introduced the Contact and Episode of Care concepts to analyze the feedback from the medical community regarding the exercise of these two concepts. Adapter components were used to connect the GP's EMRs to a very simple broker in a hub-and-spoke architecture. HL7 v.3 messages were used to communicate to a Web portal information and documents relative to contacts with GPs and episodes of care of a limited number of patients [9] The result of elicitation was not conclusive because the number of volunteer patients and care givers participating to the test was too small.

LUMIR 1 is the currently operational version of the LUMIR system. It is a distributed, component-based system focused on the interoperability, security, privacy, and reliability issues. It is a collection of layered, inter-communicating web services in a pure SOA style. On the top of the layered architecture there are local clinical applications acting as clients that use LUMIR 1 services to inform other applications and the LUMIR 1 system itself of occurrences of relevant clinical events in their environment. Information about these events can be queried to the LUMIR 1 system, too.

Fig. 5 shows the UML component diagram of the LUMIR 1 system.

To integrate client-applications in the SOA, LUMIR1 introduces an intermediate, broker-based layer of high-level common services for message communication, event notification, security, and document management. This infrastructure promotes a Standard Adapter agent extended by various specific drivers that adjust the peculiarities of any of these client-applications at the uniform, LUMIR-standard space requisites. A broker-based, hub-and-spoke distribution network guarantees message transmission and notification dispatching.

The major functions of this architecture are put in work in Fig. 6 to carry out a typical scenario that we present in the followings.

Let consider a storyboard that demonstrates the communication flow associated with the outcomes of a contact between a patient with a chronic disease as diabetes and her/his GP who is preparing a multidisciplinary care plan to improve the patient's health outcomes and quality of life. The patient was previously registered for one of the Regional Diabetes Centers and has also had an initial consultation and some subsequent follow-up meetings with a cardiologist. Following each visit at the Diabetes Centre or cardiologist the GP received notifications with the progress report on the patient.

The scenario initiates when the patient scheduled a visit with GP for an alarming health problem. GP visits the patient, and re-

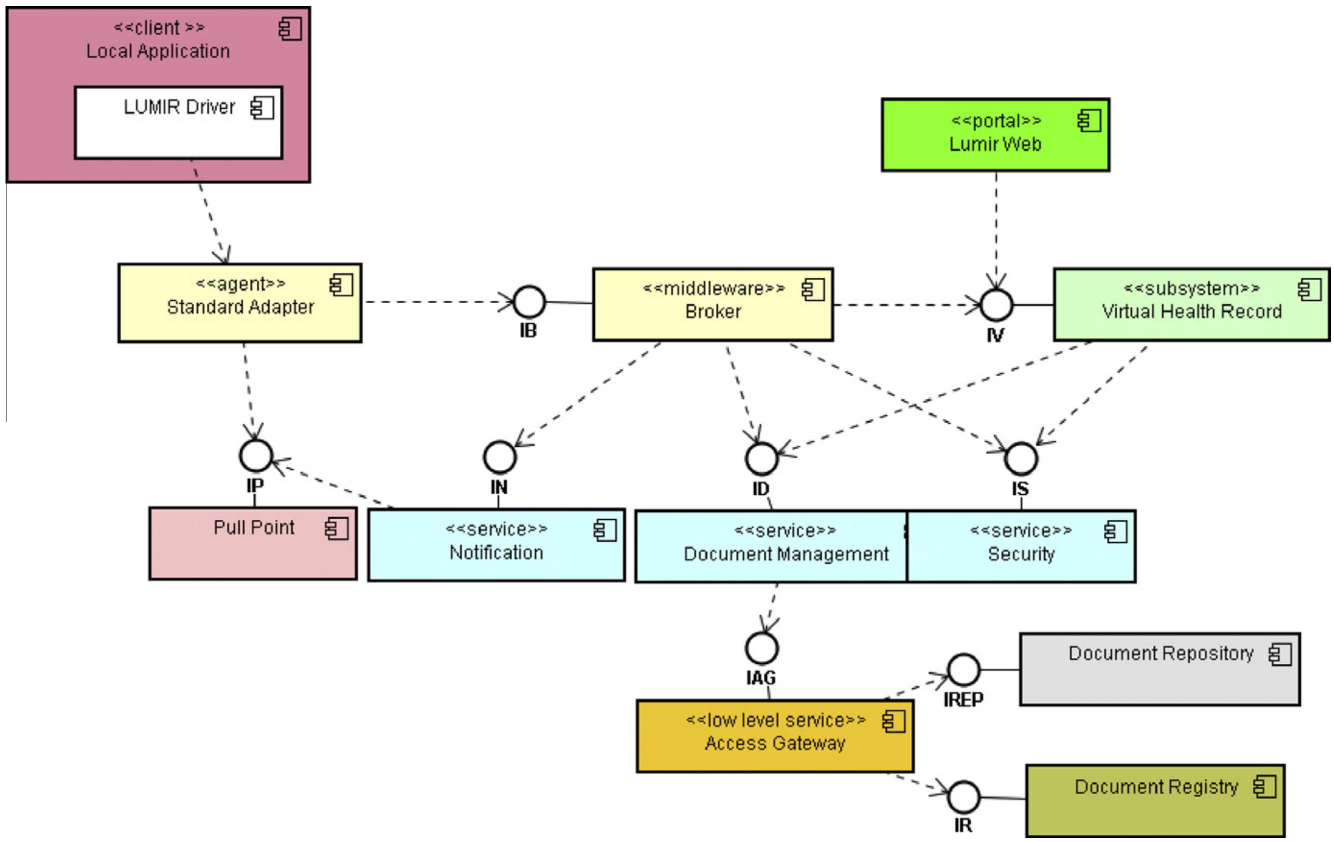

Fig. 5. LUMIR 1 component diagram.

quests a change of medication and a follow-up visit with the cardiologist with ongoing care report. According to our approach to collaborative environments in eHealth, information on the visit and provided health services should be notified to the caregivers who treat the patient: the cardiologist and the Diabetes Center. Moreover, this information should be made persistent to be successively accessed by all caregivers involved in the patient's care.

Figs. 6–8 illustrate the interactions between caregivers in the current version of the LUMIR system. In the figure, Local Application #3 represents the GP's EMR. When the patient's visit is ended the GP decides to inform the LUMIR system on what happened during the visit. For this she/he prepares all needed information that qualifies the contact, places it in the more general context of the episode of care that was caused by the health issue, in this case diabetes, and attaches two clinical documents: the drug prescription and the request for a follow-up cardiologic visit.

The Adapter component, acting as a local intelligent agent, takes over this information (1), verifies it, converts the clinical documents in HL7 CDA documents, adds the message header and digital signature, builds the M1 message (Fig. 3), encrypts the message content, and finally sends the message across an asynchronous channel to the Broker component (2).

Broker is a multifunctional component that decouples the destinations of the information in the M1 message (the applications of the Diabetes Center and cardiologist, and LUMIR web portal) from the sender (the MMG legacy application) and maintains central control over the flow of messages:

– Broker analyzes the M1 message header to obtain general information on the clinical event, extracts the attached documents from the message and calls the document management service to (3) store the documents (3.1) and register their metadata (3.2) in the repositories and the registry of the jurisdictional area of competence. The registry of the Regional Authority jurisdictional area will be automatically updated with the same document metadata in order to behave as a complete index of clinical documents delivered by the regional healthcare settings (3.3, 3.3.1).
– Broker sends the message content to the VHR (4.1) that extracts, interprets and stores the contained information in the portal's repository (4.2).
– Broker publishes the clinical event to a notification service (5).
– The notification service, according to the event topic uses a notification policy and dispatches notification messages to all destinations that subscribed for this message topic (6a, 6b, and 6c). Pull points are LUMIR components acting as notification destinations. They represent all local applications and represent precursors of the future interface agents. In the case of the LUMIR web portal a web service interface is exposed, so the notification server uses it to communicate the notification message.
– The adapters of Local Application #1 (that of the cardiologist) and Local Application #2 (that of the Diabetes Center) are polling their pull points to pull notification messages (7a and 7b). When a notification message M2 is downloaded, the adapter verifies it, notifies the local application of message arriving and offers services for notification visualization.

5. Further steps

The design and implementation of the LUMIR 2 system is in progress. It is adding mainly a multi agent platform and the VHR agent-oriented version to the LUMIR 1 system.

In its final version LUMIR 2 will make use of several services already existent in LUMIR 1: security, registry, notification and

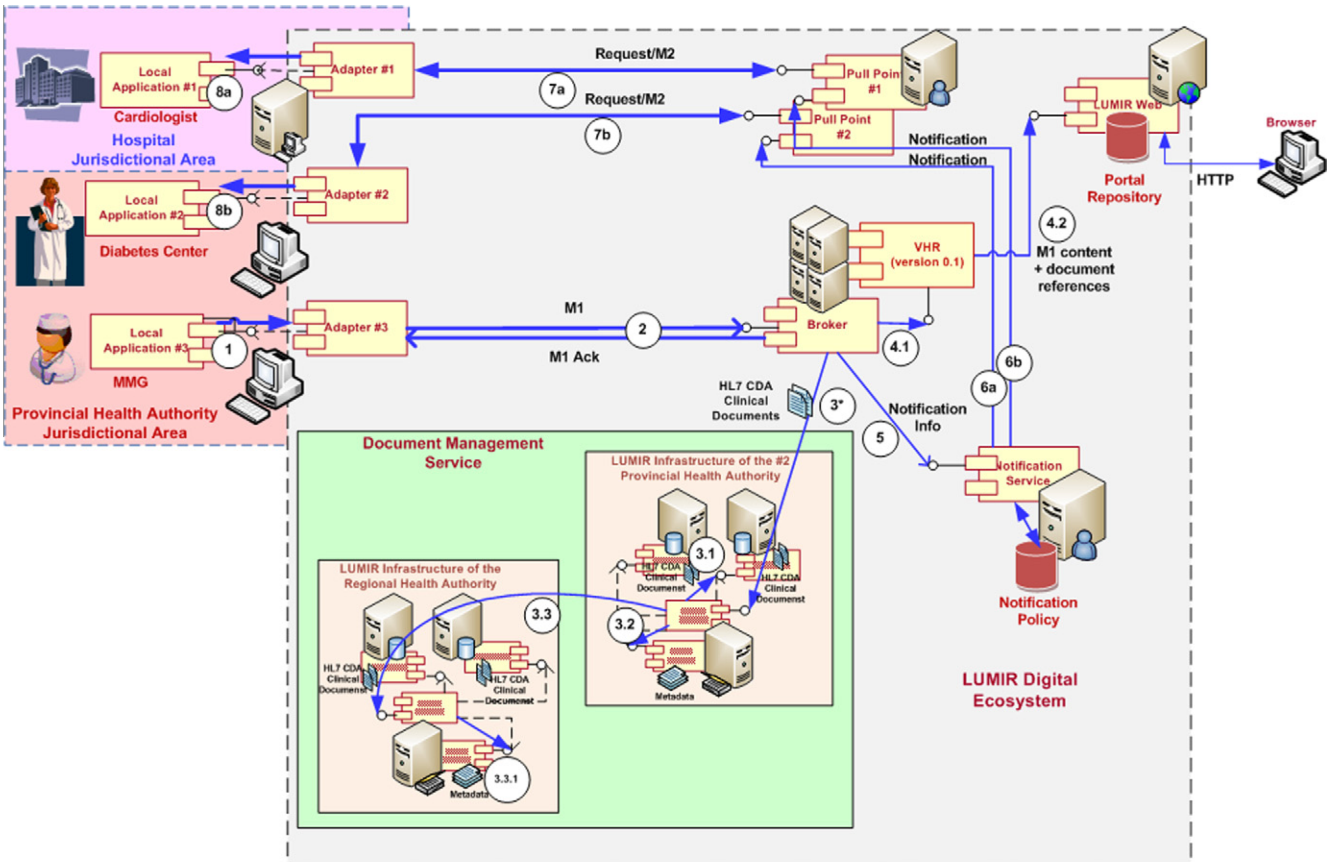

Fig. 6. Interaction scenario in LUMIR 1.

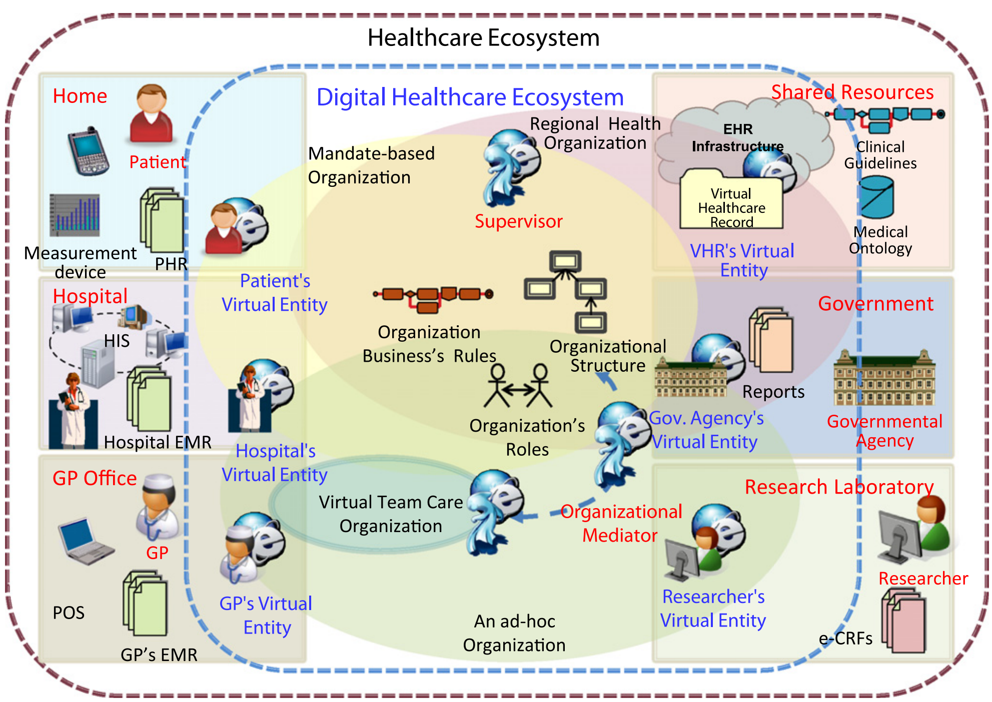

Fig. 7. Digital health ecosystem and its context.

document management, and of a powerful environment able to manage the life cycle of components and agents. In the back end a persistence service working with distributed databases will guarantee supplying data for components and agents and

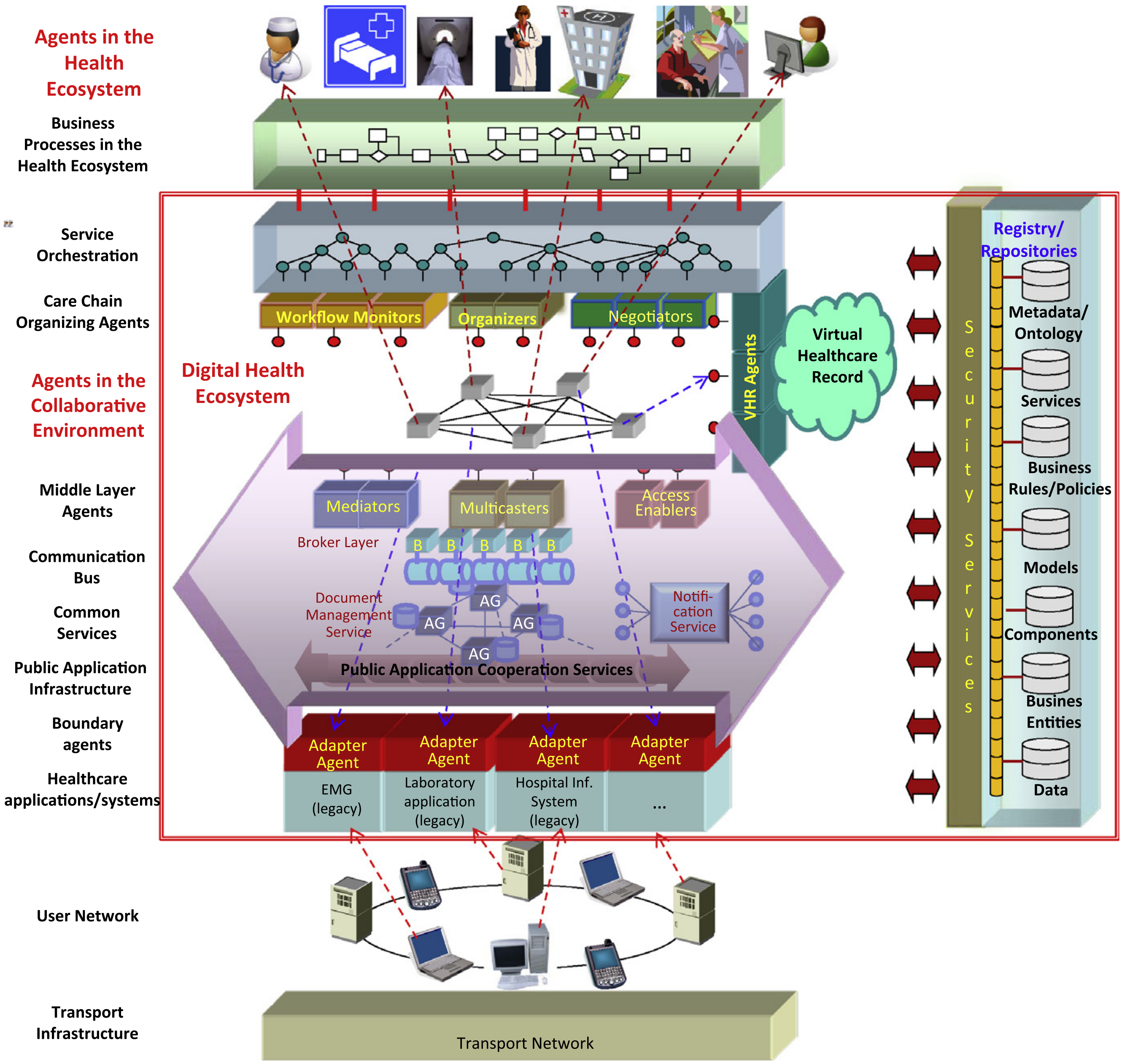

Fig. 8. The LUMIR system architecture.

saving of any new change of relevant data in components and agents.

In our design we considered the human organizations and individual behavior as appropriate metaphors to effectively assemble the LUMIR platform from a collection of heterogeneous, autonomous agents that replicate collaboration of individual physicians and healthcare organizations to solve health issues of citizens inside the regional health system (Fig. 7). We decided to implement LUMIR 2 as a MAS following an organizational approach, where virtual entities representing caregivers and patients cooperate with the VHR agents to maintain the VHR as complete and consistent as possible. In its final version the LUMIR's DHE will be an open, organized environment where agents can enter, play their role in organization and become extinct for contributing to the global aims of the organization: transporting, storing and interpreting sensitive clinical data of citizens.

In the followings we focus on stepping from LUMIR 1 to LUMIR 2.

5.1. LUMIR's "Agentification"

It is known that there is not yet a sound supporting technology nor consolidated practices in the MAS domain. Much work remains to be done for having robust tools and development environments able to deal with a great variety of agents.

Methodologies governing the development of multi-agent systems focus on discovering the agent roles, permissions, multi-agent interactions and messages. Some methodologies also take into consideration agent organizations while others focus on early and late requirements. One of the weaknesses of current methodologies is that they view organization structure and agent interactions as being static, that is specified at design-time [16]. We consider that organizations can appear ad hoc, as a reaction to changes in the environment and that agent interactions appear and disappear as agents become acquainted and share a common, temporary goal. That is why these organizations cannot be design artifacts, but in fact we must design an agent architecture able to create on the fly and evolve such organizations in the environment.

To mitigate the risks of designing and implementation of such a complex system involving interaction between parties with different objectives and concerns, we chose a stepped software development alongside an "agentification" of software components, that is a progressive evolution of the software architecture style from the component-based SOA of LUMIR 1 towards a MAS in LUMIR 2. We are planning a series of incremental iterations within the LUMIR 2 step. At beginning, the increments include new software components and gradually later their conversions in agents. Concurrently, deployment of a LUMIR-suitable MAS platform is planned.

The "agentification" of the SOA components is based on a contamination of real to virtual, and vice versa, that is while we are developing software components we must have in mind the agents that we should later obtain from these components. "Agentification" means to gradually increase the autonomy of a multi-function software component by endowing it with enough contextual knowledge to be able to make informed decisions. On an architectural level this means substituting it with an agent or breaking it down into smaller, more efficient, specialized and manageable agents which can possible be reused in different compositions. The roles and objectives of each agent are much clearer than in the case of the software component as we can follow early requirements in the development process from the inception to the implementation. As a consequence, the flexibility of the overall organization raises and the semantic gap between the abstractions belonging to the problem's conceptual model and the software entities belonging to the solution implementation is minimized.

We have pursued this approach from the early stages in LUMIR by separating the concerns, identifying discrete components and distributing them in a loosely coupled model. Also transition to an agent communication language has been made possible by using the paradigm that actors do not exchange documents but instead exchange and integrate information and knowledge on medical events. Understanding the exchanged messages among agents and across organizational boundaries is achievable by the development of the LUMIR ontology, evolving from the LUMIR domain model.

To obtain a methodological approach to the shift from a component-based to an agent-oriented architecture we are learning from the "agentification" of each software component. At present, after the conversion of the Adapter component to a cluster of three agents, we are concentrated on the Broker component.

5.2. Agent identification

In order to populate the DHE with agents that interact with the VHR, we analyzed the functionalities of and derived agent roles from the roles of persons in the health organizations and of organizations themselves in the regional health system [15]. Other agent roles were derived from the internal tasks the VHR should carry out. They interact with each other within the VHR or with agents that are external to VHR.

From analysis we found that the agents should:

- interact with the caregivers and represent them inside the LUMIR 2 system,
- interact with the medical devices and applications,
- interact with the patients for monitoring their health status as reflected in their record and recent measurements, and issuing notifications,
- supervise the execution of care plans,
- act as mediators between organizations,
- negotiate permissions, etc.

We structured the agent population in different layers and according to their functionalities we identified several agent categories:

1. *Interface agents* responsible for communicating with external systems, either human users or legacy software applications that need to be integrated in the agent ecosystem. These agents should be "bilingual", meaning to understand both agent languages and the specific interfaces of the adapted systems. They are also responsible for displaying information to the user using graphical interfaces. A specialized type of interface agent is the *boundary agent* that interacts with users (external systems as well as persons): (a) translates their requests in M1 messages and (b) receives the responses as M2 messages and adapt their information according to users' interest and preference profiles. They also act as intelligent VHR proxies on behalf of the VHR itself. The boundary agent may live in the legacy application environment and contemporarily exhibits functions of wrapper, adapter, and endpoint for the legacy applications. A prototype of such a boundary agent already acts as a gateway between the LUMIR space and the local applications in LUMIR 1.
2. *Control agents* that solve problems by coordinating and controlling other agents, sometimes specifying plans for problem-solving. In this category we have several agent types: *negotiators*, *workflow monitors*, *organizers*, but also *VHR agents*. The VHR agents act on behalf of the citizen's concerns by adding information in an authoritative, non-redundant view on her/his health state and clinical history, namely the VHR, and devising actions to be carried out by the citizen. Some VHR agents provide the citizen's VHR with authoritative and useful information about her/his health state and episodes of care by gathering, filtering, interpreting, and integrating the fresh information with the existing one. They also have the ability to interact with other digital components within the DHE, enter contextual alliances and participate in business processes in order to manage the VHR information. A special case of VHR agent is the *clinical workflow engine*. In our approach a care plan is modeled as a business process. It is composed from a list of activities or tasks and a description of the control flow where these activities are involved. Once a care plan is included in the VHR after a therapy prescription service, its execution is assigned to such a clinical workflow engine agent which supervises the realization of the care plan. The agent may advertise some tasks. For example it may advertise a notification activity to be undertaken by a *notification agent* before a scheduled procedure. Another example: consider it is critical for the patient to take a medication once a day. When deriving the care plan, the healthcare professional can mark which activity realizations are required to be acknowledged. When the medication is taken the patient marks this fact on her/his PDA or in her/his personal electronic record and successively the event is sent to the VHR clinical workflow agent.
3. *Processor agents* should receive the tasks from the control agents and execute them using the available resources.
4. *Information resource agents* should be expert agents, exposing the contents of a dedicated ontology or knowledge base to other agents. [17–19] They must be able to answer queries, for example an agent exposing a diabetes knowledge base can receive the description of the symptoms, translate them to the ontology vocabulary, query the ontology and return a match, if one exists.

5. *Query agents* that provide structured information on request by accessing heterogeneous and distributed collections of information sources.
6. *Organizational mediator agents* are created whenever an ad hoc organization is created, to support a multidisciplinary team treating a particular patient. These agents coordinate the actions of the involved provider agents, enforcing the protocols of communication and managing the encounters between avatars.
7. *Supervisor agents* which monitor the interactions of agents. They are tasked with super-organizational purposes such as improving the public health and increasing the quality of medical services. By monitoring the interactions they can synthesize trends over longer periods of time.
8. *Service agents* that carry out tasks useful for the other agent categories. In this category there are low-level service agent types: *brokers* that help to match agents that request services with agents that provide services, *access enablers* that verify permissions for accessing a resource or exchanging messages with other agents, or *multicasters* that help to dispatch notifications according to their dispatching policies.

These agents can be "instantiated" by their providing organization and dispatched where they are necessary. The manufacturing process can be made easier if we consider the agents to be constructed out of standardized, off-the-shelf software components. In such a way from a finite number of components we can obtain an infinite number of agent types, customized to each situation. These components can be:

1. *Human interfaces:* Graphical Interfaces presented to the user.
2. *Software interfaces:* Ports to other software applications.
3. *Communication*: Components able to code and decode from Agent Communication Language such as FIPA ACL [20]. Communication module accepts and interprets messages and requests originating in the environment; it also sends messages and requests to other agents in the environment.
4. *Cooperative*: Components handling negotiation, coordination, cooperation between agents.
5. *Executive*: Components executing tasks and procedures.
6. *Memory modules:* Components holding the memory of the agent: past actions, past goals and past interactions. The memory structure is specific for each agent type. With the memory part the agent is embedded in the environment, that is "senses" or "provokes" changes in the environment. These changes are fundamental for inter-agent communication.
7. *Planning modules:* may identify a set of goals and produce a plan to reach them. The plan is a process description that can satisfy the goals after its execution.
8. The Plan Interpreter Module uses the plan to keep track of the plan execution and to identify the next action to be carried out.

The roles extracted previously have a high granularity and we need to break them down into more sub-roles. We see the avatars similar to pluricellular organisms, composed of more agents, with different complexities, functions and lifespans. Each stakeholder is represented by such an organization of agents in which constituting agents are created on the fly depending the current responsibilities of the avatar. We call this organization "agent organism". We can separate this organism in two areas: a permanent statefull part containing the memory modules and goals defining the avatar as an individual part and a dynamic stateless part where standardized agents are introduced or removed.

This view has several advantages over having a complex agent for each avatar:

1. Lowers the ontological commitment of a single agent. Suppose the avatar represented a doctor that treated patients with different illnesses in different regions with different business rules. Such an agent would have to become coupled with too many ontologies and would be difficult to maintain. Instead for each new ontological commitment a new expert agent would be provided and integrated into the organism. Once that participation ended, that expert agent is passivated or removed leading us to the second advantage:
2. Highly dynamic agent organisms can react to changes in the environment by adding or removing atomic agents and redefining inter-agent collaboration. This is one way we can use the evolution paradigm from digital ecosystems at agent organization level.
3. Simpler agents can be easier to provide by other organizations when entering partnerships. In fact they can be built from standardized components.

5.3. Organizations of agents in the DHE

While the ontological uniformity of the DHE space is assured by the affiliation of the DHE's virtual entities with consistent models of health contacts, episodes of care, health services, healthcare provider roles, care plans, etc., a need of partitioning this space in jurisdictional and functional areas is evident as it results from the following examples (Fig. 7).

Consider two categories of business cases in healthcare that belong to recent trends in medicine regarding the patient-centric paradigm and patient empowerment:

1. *the management of chronic or out-patients* where cooperation of different agents belonging to several organizations is required;
2. *the proactivity of patients* where the patients are main agents and responsible for their own care management and often they should take initiative to interact with healthcare organizations or require the cooperation of different caregivers belonging to different healthcare organizations.

The control flow in such complex healthcare scenarios should be previously described in care plans and the collaboration between actors and organizations as well as the synchronization of their activities should be explicitly included in the plan. A solution to manage such complex healthcare processes is described in [14] where the Virtual Health Care Organization (VHCO) concept is introduced. A VHCO integrates all the agents involved in the care and is a partnership of different healthcare organizations by sharing with their software avatars (organizational units) knowledge, resources, data and fragments of processes. A Serviceflow Management System allows managing healthcare processes (sequences of face-to-face and virtual encounters of the patient with her/his caregivers) by coordinating activities of the organizational units. A similar approach to coordination and synchronization of activities carried out by several organizations participating in a business case is described in [21] to model the business case of a multi-centric clinical trial and in [22] to model the software process.

In fact enactment of a care plan sets up an ad hoc, temporary organization where the actors and other organizations participating in the care plan realization are agents with well-defined roles and competencies, but without an exposure of their internal business processes.

As Fig. 7 shows, the LUMIR DHE should be populated with stable and ad hoc organizations of agents that mirror either the jurisdictional areas in the real world or ad hoc delimited areas where, for instance, the privacy of stakeholders is guaranteed or – as in the case of disease networks and registries – only relatively small communities of citizens are involved. In such cases it is necessary to move from an agent-centric view of coordination and control to an organization-centric one.

We consider an organization as composed of a collectivity of agents exhibiting some explicitly specified social structures and oriented to the pursuit of a set of objectives/goals originating from its setting in a given environment [23].

Inside an organization we find agent roles, agent grouping mechanisms, types of activities to be carried out by agents and specific (if any) protocols for message exchange among agents. An organization has a structure which defines the roles and relationships between the roles, based on general organizational patterns derived from an organizational theory. This has effects on the individual agent's design as its main purpose becomes to enact a role in the organization. The organizational goals determine the agent roles and interactions, as well as the internal rules. Organizational rules (super-role requirements) can be formalized in deontic logic and their enforcement can be monitored using specific policy agents, tasked with the supervision of interactions within their authority mandate.

Due to its goal-orientation and internal regulation an organization exhibits an externally observable global behavior, independently from its participants. This is why agent organizations in the DHE require to integrate internal regulation and individual behavioral tendencies to the adaptation of models to organizational and environmental changes. Changes in the environment should be reflected in changes in the organization, that is to design flexible organizations able to conduct preemptive or proactive structural and functional modifications, to integrate new components or to abandon obsolete ones and to integrate new norms. Such an entity should incorporate more temporal dimensions, to sustain long-term growth and evolution.

The stakeholders' concerns should be carefully analyzed and matched with the general objectives in patient-centric healthcare. The internal regulation of an organization of agents can help simplifying the inherent complexity of a heterogeneous collection of autonomous agents and efficiently channel the agent behavior towards achievement of objectives. Regulations in real world organizations can hint similar regulation in the corresponding organizations of agents.

The final LUMIR overall architecture is presented in Fig. 8.

6. Expected results and impact

1. The deployment of LUMIR 1 and the expected development and subsequent deployment of LUMIR 2 have to create the necessary conditions to encourage the fundamental shift to patient-centric healthcare. We believe that this shift is a critical step to achieve the sharing and reuse of clinical information in ways that are appropriately governed and are centered on the interests of the patient, the population and the health services.
2. This project makes an original contribution to the understanding of the impact that an integrated health information system focused on the patient care process has on the expectations of the regional government, caregivers and population regarding the quality of service and containment of costs. We expect that the project contributes to improvements in service delivery at regional or local level.
3. Our team contributed to constitution of the Regional Board for eHealth and actively participated to its work. Raising awareness of problems locally or at regional level was another way in which projects had impact. We intend to change healthcare in Basilicata by creating healthcare IT solutions that are compelling and/or attractive, and that people (caregivers and care consumers) want to use. Even if the regional government launched incentive programs for promoting eHealth among the practitioners, we cannot rely only on administrative regulations. By offering stimulating solutions we must make physicians demand to use the power that IT brings to medicine.
4. The contamination of the real to the virtual in analyzing the digital healthcare ecosystems will generate in time a reflection of the virtual in the real, when solutions and resources discovered in the digital world will make their impact in the real world. Such would be the case of constructing virtual organizations in the form of multidisciplinary teams of healthcare provider virtual entities which will be followed by establishing similar relations in the healthcare organizations.
5. The transition to a digital healthcare ecosystem will also foster an increase in the quality of eHealth care services by creating a competitive open, standards-based market, where multiple vendors can publish their interoperable services and products. By choosing a component-based approach to our architecture, where composite agents are built from standard software components, we are increasing software reuse and also encourage vendors to participate in producing particularized solutions, for the heterogeneous application medium, which can be integrated in the digital environment.

7. Conclusions

The paper presents our experiences in the development of LUMIR, an integration platform for the health information system of the Basilicata region. Our research addresses the problem of enabling collaboration among agents of different types (caregivers, patients, health organizations) in a regional-wide, integrated health information system having as objective the patient-centric healthcare delivery. LUMIR facilitates communications of clinical events between local clinical applications of the healthcare users in order to guarantee a patient-centric delivery of health services. To promote collaborations and sharing clinical information among caregivers, the LUMIR system maintains a VHR for each citizen, that is an authoritative view on her/his health state. This view is obtained from messages originating in local health applications and corresponding to some significant events. These events can be clinical events if they demonstrate (or only hypothesize) changes in the patient's health state or some non-clinical events that are direct consequences of these changes. Work on VHR is still in progress as we are analyzing different technology stacks to employ in VHR implementation and are extending the definition of the messages M1 and M2 to express new functionalities and include more concepts belonging to the LUMIR healthcare ontology.

Another innovative approach in the LUMIR project is the decision to model the regional health information system as a DHE, that is a homogenous virtual world inhabited by agents that cooperate, share information and knowledge, evolve and adapt to local conditions thanks to mechanisms of evolution and aggregation in ad hoc communities. The ecosystem consents to create goal-oriented organizations of agents with organization-specific roles and interaction rules.

The agents play various roles in the ecosystem's organizations. The roles of some agents are derived from the roles of real or abstract entities in the real world (people, organizations, software applications), others represent artificially included entities aimed to implement mechanisms derived from the organization's interaction rules.

To mitigate the risks of designing and implementation of such a complex system we chose a stepped software development alongside a progressively evolution of the software architecture from a component-based approach towards a multi-agent oriented one.

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References

[1] Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions. e-Health – making healthcare better for European citizens: an action plan for a European e-Health Area; 2004. <http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:52004DC0356:EN:NOT>.
[2] http://www.nhscarerecords.nhs.uk.
[3] Swedish Strategy for eHealth; 2009. <http://www.sweden.gov.se/content/1/c6/12/48/02/a97569e9.pdf>.
[4] Dobrev A, Jones T, Stroetmann V, Stroetmann K, Vatter Y, Peng K. Interoperable eHealth is worth it. Securing benefits from electronic health records and ePrescribing, Study report. European Commission Information Society and Media; 2010. <http://ec.europa.eu/information_society/activities/health/docs/publications/201002ehrimpact_study-final.pdf>.
[5] TSE, Italian National Board for eHealth. A policy for e-Health; 2005. <http://www.sanitaelettronica.gov.it/xoops/modules/docmanager/index.php?curent_dir=39TSE-PoliticaCondivisaperlaSanitàElettronica.pdf> [in Italian].
[6] TSE, Italian National Board for eHealth. Architectural strategy for eHealth; 2006. <http://www.sanitaelettronica.gov.it/xoops/modules/docmanager/index.php?curent_dir=39TSE-IBSE-Strategia_architetturale-v01.00-DEF.pdf> [in Italian].
[7] http://www.spcoop.it/spcoopit/jsp/index.jsp.
[8] HL7, HL7 Version 3 Clinical Document Architecture. <http://hl7book.net/index.php?title=CDA>.
[9] Contenti M, Mercurio G, Ricci FL, Serbanati LD. The LUMIR project: developing the GP's network pilot program in the Basilicata region. In: ItAIS 2008: information systems: people, organizations, institutions, and technologies; 2010. Springer. p. 255–63.
[10] Serbanati LD, Contenti M, Mercurio G, Ricci FL. LUMIR: a region-wide virtual longitudinal EHR. In: 9th international HL7 interoperability conference – IHIC 2008, Crete, Greece; 2008.
[11] HL7, HL7 Version 3 reference information model version 2.29. <http://hl7book.net/index.php?title=HL7_version_3>.
[12] Nachira F, et al. Toward a network of digital business ecosystems fostering the local development; 2002. <http://www.digital-ecosystems.org/doc/discussionpaper.pdf>.
[13] http://www.digital-ecosystems.org/.
[14] Leonardi G, Panzarasa S, Quaglini S, Stefanelli M, van der Aalst WMP. Interacting agents through a web-based health service flow management system. J Biomed Inform 2007;40(5):486–99.
[15] Wooldridge MJ. Intelligent agents. In: Weiss G, editor. Multiagent systems: a modern approach to distributed artificial intelligence. Cambridge (MA): MIT Press; 2000. p. 27–79.
[16] Wooldridge M, Jennings NR, Kinny D. The Gaia methodology for agent-oriented analysis and design. J o Autonom Agents Multi-agent Syst 2000;3:285–312.
[17] Russel S, Norvig P. Artificial intelligence: a modern approach. Prentice Hall: Englewood Cliffs; 1995.
[18] Bogdan C, Luzi D, Ricci FL, Serbanati LD. Towards an ontology using a concern-oriented approach for information systems analysis. In: Enterprise interoperability II, new challenges and approaches. Springer-Verlag; 2007.
[19] Bogdan C, Serbanati LD. Concern-oriented and ontology-based analysis of information systems. In: Information systems: people, organizations, institutions, and technologies, ITAIS 2008. Springer Verlag; 2008.
[20] http://www.fipa.org/repository/aclspecs.html.
[21] Collada Ali L, Fazi P, Luzi D, Ricci FL, Serbanati LD, Vignetti M. Toward a model of clinical trials. In: LNCS 3327. Springer; 2004. p. 299–312.
[22] Serbanati LD. Integrating tools for software development. Yourdon Press; 1992. p. 8–9, 124–128.
[23] Dignum V, editor. Handbook of research on multi-agent systems: semantics and dynamics of organizational models, information science reference; 2009.