A Context-Aware Framework for Health Care Governance Decision-Making Systems

A model based on the Brazilian Digital TV

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***Abstract*— This paper proposes a governance decision-making framework for public health care systems. It encompasses and integrates data about family homes in a new intelligent health care information system. In order to support end-user interactions, the framework has been built on the GINGA middleware developed for the Brazilian Digital TV, whose full access will be country-wide in 2015. Based on five governance fields, namely knowledge, normative, clinical-epidemiological, administrative, and shared management, the framework relies on an Optical-WiMAX communication infrastructure (Brazilian Digital Belt), which will reach 82% of urban population in the Ceará State. In addition, we present a case study showing how the framework could be used for improving health care governance decisions.**

Keywords-component; Integrated Health Network, Decision-making, Middleware GINGA, Brazilian Digital Belt, Context-awareness.

I. INTRODUCTION

The increasing incidence of diseases (e.g., epidemics, pandemics, outbreaks and the like) represents a major challenge for health care systems. Resources dedicated to the patients and their associated costs put pressure on such systems to meet demand. In order to address this issue, many advocates for using innovative clinical approaches, including a bigger involvement of patients and the systematic monitoring of their conditions, rather than simply treating acute problems [1].

Information technology (IT), through to its ability to monitor and remotely interact with patients and caregivers, has attractive qualities for this role [2]. For instance, home telemonitoring applications could be used for exchanging health condition data between family homes and health professionals, improving coordination and effectiveness of primary health care. Telemonitoring could result in the decrease of emergency visits, hospital admissions, and the average hospital length of stay. In this scenario, Digital TV (DTV) [7][8] devices could be used as an efficient technology for home telemonitoring. In fact, using DTV and a feedback channel one can set up a bidirectional communication for exchanging data between family homes and health care teams. DTV devices (i.e., Set Top Box) can be adapted to retrieve clinical condition information of family members captured by sensors (e.g., heart rate, pulse, blood pressure), sending it to the responsible health care team. We called this data *health context information* and it can be exploited by health care systems for improving decision-making support. For example, when health conditions of monitored patients are deteriorating, the health care system could provide alerts and decision support for both patients and clinical team. Health care teams are also able to access remotely patient's health data, allowing them to react appropriately to changes.

At a higher level, health context information could be exploited by health care governance applications for improving their decision-making support. Health care governance [4] refers to the guidance role of all regulatory, administrative, professional, and clinical sectors in the achievement of collective goals (e.g., controlling an epidemic). Through a variety of organizational arrangements, social, and relational processes, health care governance standards contribute to the achievement of "public goods".

This paper proposes and discusses a context-aware framework for health care governance decision-making systems called LARIISA. In order to support telemonitoring facilities and end-user interactions, the proposed framework is built on top of the GINGA middleware developed for the Brazilian Digital TV [9].

The reminder of paper is organized as follows: Section II discusses the motivation of this work in a typical application scenario. Section III presents the LARIISA framework and governance setting for decision-making support. Section IV shows a case study in a real scenario. Section V presents related work. Finally, Section VI concludes the paper and discusses future work.

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II. TECHNICAL BACKGROUND AND MOTIVATION

We have experienced a governance decision-making scenario that serves to illustrate the functional requirements of LARIISA framework. In 2008, the Brazilian cities were affected by a major Dengue epidemic. As all the Brazilian cities, Fortaleza[1] had taken the general control procedures and specific measures for this situation. Dengue epidemic was controlled in Fortaleza thanks to a series of governance decision, which are reported by the Health Secretary who led the process:

"Once we realized the lack of a system able to provide reliable data and information in real time, offering correct information for making decisions, we have decided to transfer the Office of Health Secretary and his staff to the Control Center of Endemic Diseases and Zoonoses. This decision made possible the creation of a Situation Room, allowing an effective monitoring of Dengue and consequently controlling this disease."

In the scenario above, such decision allowed health officials to obtain real-time health context information (Local and Global Health Context) for improving governance decisions. Another important aspect to be considered in this case is the medical training of Health Secretary and his public health experience, political, social, and administrative expertise (Health Manager's Profile). Positive indicators enabled the Brazilian Ministry of Health to recognize the efficiency of health system in Fortaleza. Therefore, it is necessary to propose intelligent mechanisms to help health managers for making good decisions in similar situations, which is the main purpose of LARIISA framework.

III. LARIISA FRAMEWORK

LARIISA is centered on the concept of health context information. Based on Dey's definition of context [5], we have defined health context as *any information that can be used to characterize the situation of an entity in a health system. An entity is a family member, health agent, health manager, etc. that is considered relevant to the interactions between a user and a health system in order to make decisions.* LARIISA is being specified taking into account specific requirements of five governance fields: Knowledge Management, Systemic Normative, Clinical and Epidemiology, Administrative, and Shared Management. We present in the next subsections the health context models (i.e., local and global health context) defined for representing health context information and the health governance fields described by means of examples.

A. Health Context Model

It is necessary to define a formal health context model in order to facilitate context representation, sharing, and semantic interoperability in the health care governance system. For this purpose, we have defined two OWL-DL[2] ontologies for modeling local and global health context information, respectively. *Local health context* (Figure 1) describes the situation of any entity interacting with the governance system, such as end-users (patients), health managers, health agents, etc. This information is used for defining local health decision rules and for deriving global health context information. *Global health context* (Figure 2) describes high-level information derived from local health context that is used for making health governance decision. For example, it describes the number of Dengue cases confirmed in a region (e.g., neighborhood, city, community), during a given period of time (e.g., a day, a week). In fact, such information can be seen as global indicators used for improving governance decisions.

Based on the *Context top Ontology* we proposed in a previous work [14], we classify local and global health context information according to five dimensions (Figure 1 and Figure 2 illustrate partially the proposed ontologies): *spatial* - any information characterizing the situation from spatial dimension (e.g., location, place, GPS coordinates); *temporal* - any information characterizing the situation from time dimension (e.g., timestamp, interval, period of day, month, year, day, season); *spatio-temporal* - any information characterizing the situation that is dependent of both spatial and temporal dimensions i.e., weather conditions, temperature, noise, luminosity; *social* - any information characterizing the situation from social relationships; *computational* - any information describing the situation from the computational characteristics (e.g., user device's capacities). Moreover, we have added a new dimension named *health_Element* for classifying context information from the health point of view (e.g., heart rate, pulse, blood_pressure). We are reusing GeoRSS[3] concepts to describe GPS coordinates and spatial geometric relations, and OWL-Time[4] to express temporal content. From the Context concept described in the *Context Top Ontology*, we defined two subclasses named *Global_Health_Context* and *Local_Health_Context* (i.e. Global_Health_Context $\cup$ Local_Health_Context $\subseteq$ Context). These concepts capture from the context any information characterizing the situation that is relevant for improving health care governance decisions, i.e. it can be used for defining local and global health decision rules. We use as basis the ECA model (Event-Condition-Action) [15] for describing global and local decision rules that are translated into SRWL[5] rules. The Event represents the identification of changes on the context, Condition describes a set of valid context constraints, and the Action describes the decision.

B. LARIISA Governance Setting

1) Knowledge Management

Definition: It comprises strategies/practices used by organizations for identifying, creating, and representing health care experiences. These strategies/practices are used for maintaining and transferring those experiences by using formal research and empirical processes, and other ways for generating new knowledge and improvements.

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[1] This city is the state capital of Ceará (Brazil).

[2] http://www.w3.org/TR/owl-guide/

[3] http://www.georss.org/

[4] http://www.w3.org/TR/owl-time

[5] http://www.w3.org/Submission/SWRL/

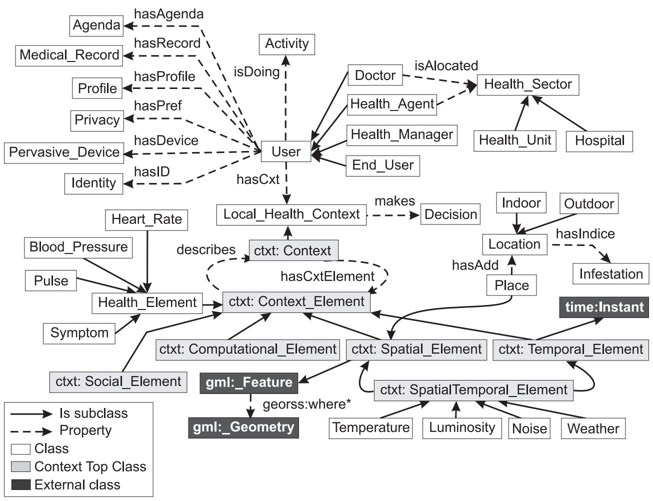

Figure 1. Local health context model

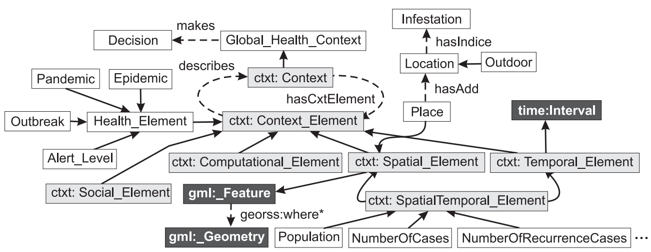

Figure 2. Global health context model

<u>Example of governance decision</u>: Creating an Emergency Room (ER) to the clinical management of severe case (ER-SC).

<u>Example of global decision rule:</u>

IF ((numberOfDengueRecurrenceCases(region Y, period Z) > X) **THEN** {Alert: to create an ER in the region Y}

<u>SWRL rule:</u>

Global_Health_Context(?ghc) ^ Location(?Y) ^ time:Interval(?Z)
^ hasContextElement(?ghc, ?Y)
^ hasContextElement(?ghc,?Z)
^ NumberOfRecurrenceCases(?W) ^ hasContextElement(?ghc,?W)
^ swrlb:greaterThan(?W,X)
➔ MakingDecision(?ghc,"Alert: to create an ER in the region Y")

<u>Example of local decision rule</u>:

IF ((the patient has contracted Dengue more than once) **AND** (she lives in an area of high infestation indices) **AND** (she has symptoms *A,B,C*))
THEN {the patient must consult the ER-SC about this case}

<u>SWRL rule:</u>

End_User(?patient) ^ Local_Health_Context(?lhc)^Location(?region)
^Infestation(?deng) ^ Symptom(?A) ^ Symptom(?B) ^ Symptom(?C)
^ Medical_Record(?dengue)
^ hasContext (?patient, ?lhc)
^ hasRecord(?patient,?dengue)
^ swrlb:greaterThan(?dengue,1)
^hasContextElement(?patient, ?region)
^hasIndice(?region,?infestation)
^hasContextElement(?patient,?A) ^hasContextElement(?patient,?B)
^hasContextElement(?patient,?C)
➔ MakingDecision(?lhc,"Alert: the patient must consult the ER-SC about this case")

<u>Result</u>: Executing these rules, we were able to reduce the mortality indices caused by Dengue.

2) Systemic Normative

<u>Definition:</u> It refers to the participation of public officials and health managers for using and drafting laws in order to generate standards for consistency, concreteness, and certainty of health systems.

<u>Governance decision example</u>: Assessing the value and application of sanctions envisaged in the Law X.

<u>Example of local decision rule</u>:

IF ((the waste deposit of an establishment did not obey the law) **AND** (it is a recidivist))
THEN {Alert: to apply the fine and close the establishment}

In this case, when an inspector visits a waste deposit of an establishment and identifies irregularities, from his mobile device he is able to access the system and update it with this information. Enforcing local decision rules the system is able to identify this event, checking if it is a recidivist case. If this is the case, the inspector will receive an alert to apply the fine and close the establishment.

<u>Result</u>: Several waste deposits have been warned, some were closed and many have improved significantly.

3) Clinical and Epidemiology

<u>Definition:</u> it ensures the knowledge of health-disease processes, from the concept that health is determined by biological, social, economic, genetic, and lifestyle factors, influencing the service of health care systems.

<u>Governance decision example</u>: Implantation of intravenous hydration procedure in the health units of districts.

<u>Example of global rule example</u>:

IF ((there are cases of disease re-infection in the districts) **AND** (there are indicators of epidemic disease))
THEN {Alert: to create in the health unit a new intravenous hydration procedure and classify that district in red alert}

<u>SWRL rule:</u>

Global_Health_Context(?ghc) ^ Location(?district) ^
time:Interval(?inter) ^ Epidemic(?dengue)
^ hasContextElement(?ghc, ?district)
^ hasContextElement(?ghc,?inter)
^ NumberOfRecurrenceCases(?cases) ^
hasContextElement(?ghc,?cases) ^ swrlb:greaterThan(?cases,0)
^ hasContextElement(?ghc,?dengue)
➔ MakingDecision(?ghc," to create in the health unit a new intravenous hydration procedure")
Alert_Level(?red) ^ hasContextElement(?ghc,?red)

<u>Result:</u> Improving the management of severe cases in the Hospitals, transferring the flow of care to the health units.

1) Administrative

<u>Definition:</u> it refers to the act of directing professionals for accomplishing a determined goal and the responsibility for maintaining/supervising the entities related that goal.

<u>Governance decision example</u>: Allocating trained professionals, strengthening the training and recruiting them to the situations.

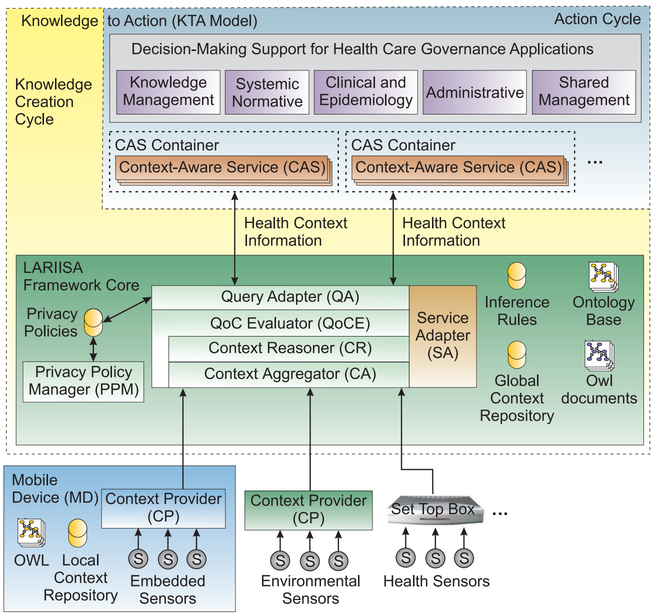

Figure 3. LARIISA Framework Core and Health Care Governance Decision-Making Applications.

Example of global rule:

IF (the global quantity X of trained professionals) < (amount of trained professional in the hospitals and health units)
THEN {Alert: request *M* new employees and train *N* professionals in *X, Y, Z* skills}

SWRL rule:

Local_Health_Context(?lhc) ^ User(?professional)
^ hasContext(?professional,?lhc)
^ (< X Health_Unit)(?professional)
^ (< X Hospital)(?professional)
➔ MakingDecision(?ghc,"Alert: request *M* new employees and train *N* professionals in *X, Y, Z* skills")

Result: Mobilization of professionals from Municipal Health School, reallocating resources originally assigned to other lower priority sectors.

2) *Shared Management*

Definition: it refers to the ability of knowledge sharing in health systems, providing global management visions of internal processes, government skills, society experiences, and their representative institutions, keeping a harmonic relationship with other federal states and international entities.

Governance decision example: Mobilization of Civil Society and health organizations for creating a Special Committee.

Example of global rule:

IF ((the building is in construction for more than *X* months) **AND** (it is located in an area where the disease infestation > 50%))
THEN {this building is being included in the "red list" for monitoring by the Special Committee}

When an inspector visits a region with outbreak of Dengue, if he finds a building under construction with more than X months, he will update this information in the system by using his mobile device. The system, from enforcing local decision rules, will include this building in the red list for monitoring by the Special Committee.

Result: Decreasing infestation rates and increasing involvement of civil society.

C. *Knowledge to Action (KTA) model and LARIISA*

LARIISA framework should provide context-aware facilities for each set of involved users (e.g., end-users, health managers, and health agents). On the one hand, the framework should consider the requirements of governance decision-making process in order to achieve a more effective and integrated health care system. On the other hand, generally there is a gap between knowledge creation, context detection, and knowledge application processes. This problem was identified by Graham *et al.* in [6], where they propose a *Knowledge to Action* (KTA) model in order to discuss issues in each step of two cycles: i) knowledge creation cycle; ii) action cycle. KTA model was designed to help practitioners, researchers, policy makers, patients, and the general public to understand how knowledge and practice in health systems interact and influence each other.

Knowledge comes from various sources and includes both personal experience and researching. The authors suggest that knowledge creation is an adaptation process, where research questions are designed for addressing problems identified by users, while research results and its dissemination are tailored to meet the needs of specific audiences. In the action cycle, the authors use theory of planned action (models) for describing what happens in the cycle. These models are used to predict the likelihood of changes. Graham *et al.* suggest eight models may help research into action (see more details in [6]).

LARIISA offers context-aware mechanisms for reducing the gap in the knowledge transfer process to the action cycle. Similarly to the creation knowledge and action process in the Graham's model, there is a gap between health context detection for adapting the knowledge to the local/global situation and how this context affects the related health applications (Action). However, we are able to reduce this gap offering context-aware adaptation mechanisms for each step of action cycle.

Knowledge creation cycle of KTA model can also adapt their processes taking into account health global context information. We consider this cycle more complex than the Action Cycle. We suppose it has specific dynamic characteristics, which could be assisted by intelligent systems, independently of Action Cycle. Therefore, it is beyond the scope of capability implemented by the entities of LARIISA framework.

D. *LARIISA Framework Core*

Figure 3 presents the LARIISA core architecture. It extends our context management framework proposed in [15], integrating new components (e.g., Service Adapter) for adapting knowledge used by health care applications. The components of LARIISA are described in the following:

- **Context Provider (CP):** it is in charge of gathering raw healthcare context data from the environment, mobile sensors (e.g., health agent's mobile device), and family homes (i.e., by using Set-Top Box), which will be sent to the context aggregator (CA) layer. These sensors could be physically connected to the Set-Top Box of Brazilian Digital TV or they could establish an external connection (e.g., through WIMAX, GSM/GPRS/3G and the like) with the system for transmitting the gathered context data. We have used the Diga Ginga system implemented in a previous work [7] for gathering user-end vital signs by sensors integrated with the Set Top Box, such as corporal temperature, heart rate, pulse, respiratory rate, and blood pressure;

- **Context Aggregator (CA):** it is in charge of receiving health context information from various context providers, running context aggregation operations in order to have useful high-level context represented by the Local Health Context Ontology;
- **Context Reasoner (CR):** CR runs inference/derivation processes on health context information described by Local Health Context instances in order to obtain semantic high-level context information and to generate Global Health Context information. For instance, it is able to infer a situation of epidemic (i.e., Global Health Context information) from Local Health Context obtained from family homes and by health agents. It uses SRWL for describing inference/derivation rules;
- **QoC Evaluator (QoCE):** it evaluates the Quality of Context (QoC) information [15], generating QoC indicators assigned with each context concept that will be used for improving health care governance decisions (e.g., precision and up-to-datedness of location);
- **Service Adapter (SA):** it is the main layer of LARIISA. It is in charge of identifying health context information relevant to the three following cycles: i) knowledge creation process; ii) health care governance decision-making process; and iii) health care actions. Moreover, it handles the following functions: (i) context-aware adaptation of health local decision rules, taking into account governance decisions (top-down adaption); (ii) context-aware adaptation of health local decision rules, taking into account the local health context; (iii) offering context-aware health indicators describing global health context to the knowledge creation entities and governance decision-making applications (bottom-up adaptation). It is in charge also of enforcing automatically global and local decision rules by using Pellet[6].
- **Context-aware Service (CAS):** it uses Local and Global Context information obtained from the Service Adapter for adapting their functionalities. Context-aware services will compose health care governance decision-making applications designed according to the Action Cycle of KTA model;

[6] http://clarkparsia.com/pellet

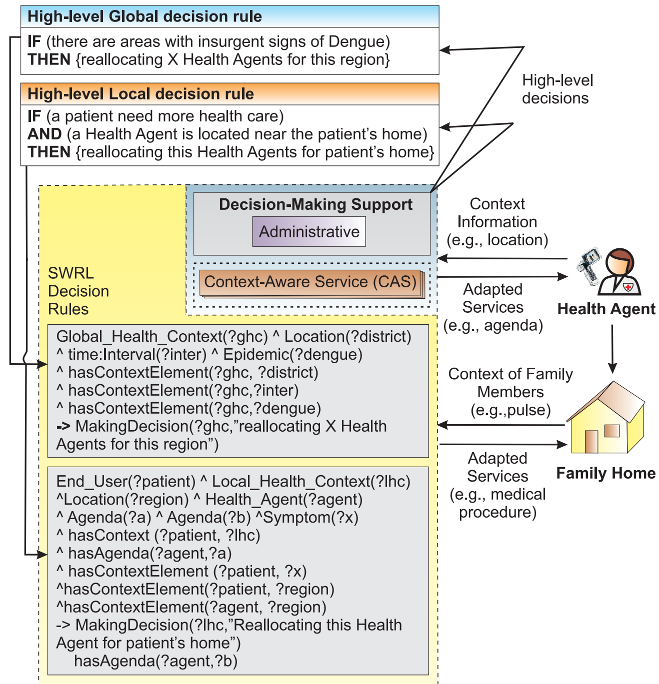

Figure 4. Case Study: Health Agent scheduling.

- **CAS Container (CasC)**: it represents a group of CAS. A governance decision-making application is composed by one or more CasC;
- **Query Adapter (QA):** it handles context queries from context-aware services and entities of knowledge cycle, extracting relevant context information from the *Context Global health Repository*. The privacy policies protecting context information are stored and enforced by the Privacy Policy Management (PPM).

IV. Case Study: Health Agent Scenario

Let us consider the Health Agents that deals daily with users of health care system, visiting family homes and communities (see Figure 4). Without an information system, the visiting schedule of Health Agents follows a linearity and not efficient agenda. The idea in this case study is to improve the quality of health services provided by health agents. It can be achieved, for instance, adapting health agent's agenda to the current situation. Health agents could be recruited for visiting an area where there are insurgent signs of Dengue (i.e., Global Health Context) or people that need health care (i.e., Local Health Context). We identify two administrative decisions: i) Adaptation of Health Agent's agenda taking into account Global health context (i.e., global decision rule); ii) local adaptation of agenda taking into account only local health context information (i.e., local decision rule). Figure 4 illustrates these two rules described by SWRL decision rules, which will be enforced by the *Service Adapter* component, adapting the Health Agent's agenda.

V. RELATED WORK

To the best of our knowledge, none of existing approaches [10][11][12] propose context-aware governance decision-making support for public health care systems. However, several research studies aim at using context-aware technologies to improve health care information systems.

In [10] Jih et al present a Context-Aware Service Integration System (CASIS). Context-aware services have been developed using context technologies and mobile web services in order to help enhance the quality of health care systems. In [12] Gu et al. proposed an ontology-based Context Management System (CMS) that allows users to define contexts using terms from medical fields. However, a generic or 'one-size-fits-all' approach does not meet specialized requirements of sophisticated and complex health care systems. Similar to those studies, LARIISA is based on classical mechanisms for knowledge management. The main difference is that LARIISA takes into account specific requirements of health care governance decision-making applications. Moreover, it has been specified using as basis the KTA model [6], reducing the gap in the knowledge transfer process for health care applications. It has been achieved by using Digital TV [13] and context-aware technologies built on the Brazilian Digital Belt [3].

VI. CONCLUSION AND FUTURE RESEARCH

Western society has built its health care systems centered in hospitals, where the output is coming back to the family homes. In this scenario, we propose a context-aware framework (LARIISA) for health care governance systems, which uses the Set-Top-Box of Brazilian Digital TV installed on family homes for supporting telemonitoring applications, remote medical procedure, etc. In addition, we have shown how the framework could be used for improving decisions on five governance domains: Knowledge Management, Systemic Normative, Clinical and Epidemiology, Administrative, and Shared Management.

In order to verify the viability of LARIISA, a large-scale trial will be conducted in Ceará state (Brazil) [3]. Moreover, a prototype has been implemented, providing the interface between end-users and the Digital Belt Project via Ginga middleware [7]. We plan yet to address the following issues: knowledge representation of medical procedures and medical tests, adapting them to the context; scalability tests; resolution of conflicting rules; and tools for helping users (e.g., health managers) in the task of describing global and local decision rules. For the scalability tests, we intend to use the SensLAB[7], which is a very large scale open wireless sensor network platform (1024 nodes) distributed among four cities in France (Rennes, Strasbourg, Lille, and Grenoble), whose deployment scenario has similar characteristics (e.g., scale, management of distributed context information).

[7] http://www.senslab.info/index.php/Main_Page

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REFERENCES

[1] T. Bodenheimer, E. Wagner, and K. Grumbach. Improving primary care for patients with chronic illness. JAMA. 2002;288:1909-1914.

[2] G.J. Young, M. Meterko, H. Beckman, E. Baker, B. White, K.M. Sautter, R. Greene, K. Curtin, B.G. Bokhour, D. Berlowitz, and J.F. Burgess, "Effects of Paying Physicians Based on Their Relative Performance for Quality," *Journal of General Internal Medicine,* Vol. 22, No. 6, June 2007 pp. 872—876.

[3] Cinturão Digital – Governo do Estado do Ceará, Available at: http://www.ceara.gov.br/portal_govce/ceara/governo/projetos-estruturantes-1/cinturao-digital, 2010.

[4] J.L. Denis, F. Champagne, and M.P. Pomey. Towards a Framework for Analysis of Governance in Health Care Organisations ans Systems. CCHSA. Université de Montreal. 2008.

[5] A.K. Dey, D. Salber, and G.D. Abowd. A Conceptual Framework and a Toolkit for Supporting the Rapid Prototyping of Context-Aware Applications. Article for Special Issue on Context-Awareness, 2001, pp. 97–166.

[6] I.D. Graham, J. Logan, M.B. Harrison, S.E. Straus, J. Tetroe, W. Caswell, and N. Robinson. Lost in Knowledge Translation: Time for a Map? Journal of Continuing Education in the Health Professions, Volume 26, 2006, pp. 13–24..

[7] M. Oliveira, and P.R.F. Cunha. Implementing Home Care Application in Brazilian Digital TV. IEEE GIIS Global Information Infrastructure Symposium. Tunisia, 2009.

[8] L.F.G. Soares, and G.L. Filho. Interactive Television in Brazil: System Software and the Digital Divide. In Proc. of EuroiTV 2007.

[9] L.F.G. Soares, R.M. Rodrigues, and M.F. Moreno. Ginga-NCL: the Declarative Environment of the Brazilian Digital TV System. Journal of the Brazilian Computer Society - Vol 13 - Number 1. 2006.

[10] W. Jih, C. Huang, and J.Y. Hsu. Context life cycle management in smart space environments. In ICPS09-AUPC2009, July 2009, London, UK, pp. 9-144.

[11] J. H. Jahnke, Y. Bychkov, D. Dahlem and L. Kawasme, "Implicit, Context-Aware Computing for Health Care",http://www.ics.uci.edu/lopes/bspc04-documents/Jahnke.pdf, 2004

[12] T. Gu, Z. Kwok, K. K. Koh, and H. K. Pung. A Mobile Framework Supporting Ontology Processing and Reasoning, Proc. of the 2nd Workshop RSPSI - Ubicomp '07, 2007, Austria.

[13] M. Oliveira, M. Tonieto, J. Faustino, and C.O. Moura Filho. Pirambu Digital: a Social Inclusion Project using IT. IFIP I2TS IX World Conference in Computing on Education. PortoAlegre (Br), 2009.

[14] W. Viana, J. B. Filho, J. Gensel, M. Villanova-Oliver, and H. Martin. A semantic approach and a web tool for contextual annotation of photos using camera phones. In WISE, pages 225–236, 2007.

[15] J. Bailey, A. Poulovassilis, and P. T. Wood. An event-condition-action language for xml. Proc. of the 11th international conference on World Wide Web, 2002, pp. 486–495, New York, NY, USA, 2002.

[16] J. B. Filho, A. D. Miron, I. Satoh, J. Gensel, and H. Martin. Modeling and measuring quality of context information in pervasive environments. In 24th IEEE AINA, 2010 (to appear).