Healthcare Tomorrow: Toward Self-adaptive, Ubiquitous and Personalized Services

Diletta Cacciagrano, Flavio Corradini, Rosario Culmone, Emanuela Merelli, Leonardo Vito
UNICAM - School of Science and Technology, Computer Science Division,
Via Madonna delle Carceri 9, 62032 Camerino, Italy
{*name.surname*}*@unicam.it*

***Abstract*—Ubiquitous computing is shifting welfare for elderly from traditional models, like family and in-hospital care, toward self, mobile, home and preventive care. This evolution is expected to be supported by Ambient Intelligent systems, embedded in smart homes and providing personalized services at the right time, place and manner.**

This is the vision of our proposal, an innovative methodological approach for designing and developing personalized and ubiquitous healthcare services that autonomously adapt at run-time to changes of the user needs and of the environment where he lives, so that improving the quality of its life.

***Keywords*-Ubiquitous computing; Self-adaptive systems; Ambient Assisted Living; Semantic Web.**

I. Introduction: the need of new delivery models for healthcare

Due to a substantial decline in the age-specific mortality of people within the last 50 years, elders have become the fastest growing age segment in most European populations. With advancing age, older people are increasingly likely to suffer from various conditions which can impair independent living.

Community care policies and socio-cultural values make family care the predominant model of welfare support for elderly people across Europe. This model also fulfills the wish of many elders, who prefer to safely live at their home, keep their own social context, socialize with family members and friends, and cultivate their own interests and hobbies. Within a familiar home environment they receive support for their loneliness and possibly for their chronic illnesses.

During recent years, however, the global increase in divorce rates, family mobility, women in the workforce and higher average age of retirement for women have altered family patterns and, as a consequence, it is becoming unfeasible to provide care to the elderly according to the classical model. Furthermore, governments are under economic pressure to keep under control the costs of the public welfare system, that is usually committed to providing in-hospital care, day services, institute-based respite care, holiday respite and home-based sitting services.

Information and Communication Technologies (ICT) are expected to address this challenge by supporting a paradigm shift in welfare delivery focused on the autonomous citizen and on the independent and high quality living model, so that alleviating pressure on the overburdened welfare system as well as satisfying the involved users.

This can be achieved only providing a new generation of services that distinguish from traditional ones for their ability to be *personalized* (i.e., customized to the specific individual needs), *self-adaptive* (i.e., able to adapt, at run-time, to changes of the user needs), *ubiquitous/pervasive* (i.e., available at any place and at any time).

The integration of different technological approaches, such as mobile computing, social networking, sensing components, knowledge management, Semantic Web, can fulfill the above requirements and also provide a context-aware world of ubiquitous computing, as described in [1].

A. Contribution of the paper: a methodological approach for personalized, self-adaptive and ubiquitous services

Our aim is to support a paradigm shift in welfare delivery focused on the autonomous citizen and on an independent, high-quality living model. We address this challenge merging social networking, pervasive/ubiquitous computing, self-adaptiveness, workflows and Semantic Web (see Figure 1) in a 3-layered methodological approach (see Figure 4) for designing and developing personalized and ubiquitous healthcare services, able to autonomously adapt at run-time to changes of the user needs and of the environment where he lives.

The first feature to be noticed, is what and how data are extracted and collected from the environment. The *Application Layer* aims at extracting and gathering sufficient information of the user's environment through a number of *pervasive* (i.e., sources of information by static and mobile ICT devices enabling innovative environment functionalities) and *social sensors* (i.e., sources of information that can be identified in modern social networking and Internet services expressing some situation and fact about users).

Another interesting feature is the way how input data (i.e., data coming from the Application Layer) are managed, organized and constrained (in our case, conceptualized in a *Conceptual Model* by suitable domain ontologies) in the *Logic Layer*, as well as processing and elaborated in the *Physical Layer*.

A domain expert platform, integrating a Semantic Knowledge Management System (SKMS) with a Semantic Work-

 ISBN: 978-1-61208-171-7

Figure 1. A new model for healthcare delivery.

flow Management System (SWMS)[1] allows domain experts to specify services as semantic-driven personalized workflows, which can be i) executed in the Physical Layer as multi-agent systems, ii) conceptualized as a procedural knowledge in the Logic Layer and iii) published in the form of SaaS (Software as a Service) in the Application Layer.

The core of the proposed approach is a reasoning and planning engine (Figure 3 (a)). It is based on an adaptive planning solver and on decision making algorithms (Figure 3 (b)). Thus, the engine can provide personalized and adaptive services at run-time, i.e., specific solutions are given to reach the same user goal depending on its continuously changing needs and states. For instance, if the service is a Web Service, then the planning solver can exploit the run-time orchestration of services, with the aim of delivering the best service for the user under consideration and according to its current context.

B. Plan of the paper

Section 4 briefly describes the 3-layer architecture of our approach and its subsequent technology. Section III is fully devoted to describe the core of the approach, namely the reasoning and planning engine. A possible application of our approach is described in Section IV. Finally, Section V closes the paper.

[1]The platform is actually available for the bioinformatic domain at `http://cosy.cs.unicam.it/ubiolab`. Currently, we are defining the Conceptual Model for the healthcare domain.

II. The Architecture for Managing User-Centric Self-Adaptive Services

In the following, we describe in detail Figure 4, which illustrates the functional architecture of the proposed approach, together with its subsequent technology.

A. Application Layer

Mobile devices are nearly ubiquitous and can be leveraged to provide location and announce a user's identity/presence in a room or place. In addition, mobile smartphones, enhanced with a variety of sensors (accelerometers, microphones, cameras, and even digital compasses) can be mined to infer actions or even orientation.

Static sensor networks embedded in the local smart space can obtain temperature, humidity, infrared, audio and video, to more fully characterize the individual's context.

Thin RFID devices, which can be easily attached to either people or objects, can be used for tagging and locating objects in the space using fixed readers (special-purpose radios) and, as a natural consequence, can be exploited to statically prevent/detect dangerous spatial/temporal object configurations [2].

However, pervasive devices alone cannot provide a full picture of the context, and in particular have a difficult

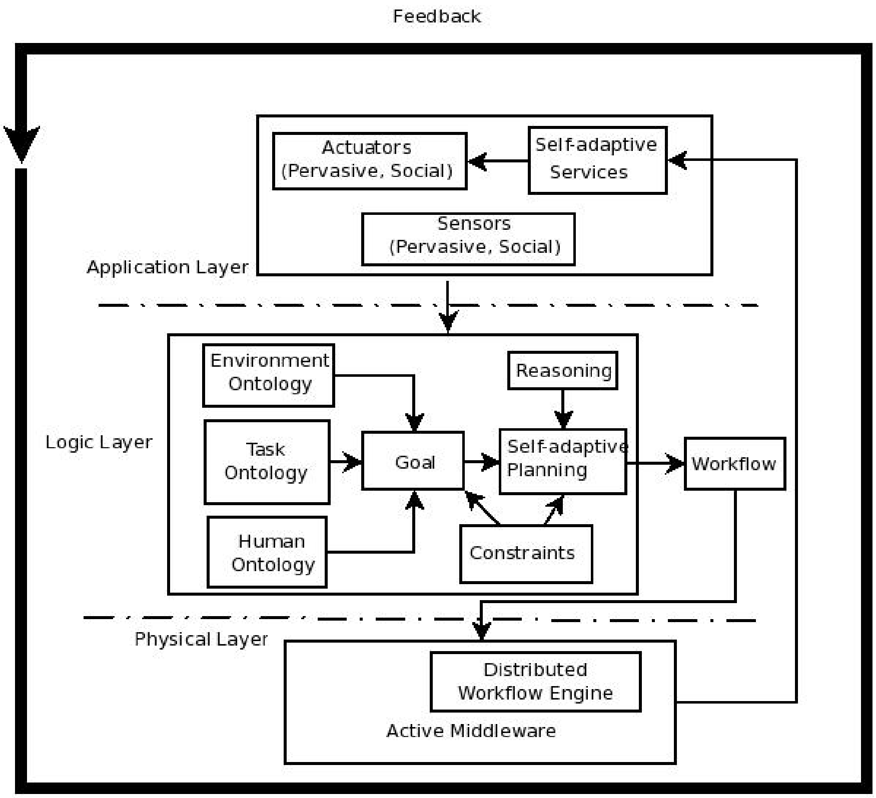

Figure 2. High level multilayer architecture of our methodological approach.

time inferring an individual's tastes. On the other hand, social networks (like Facebook, Twitter, MySpace, LinkedIn, etc.) are rich with detailed contextual information describing individual's personal interests and preferences as well as friendship relationships.

All two classes of pervasive and social sensor data, when temporally archived, provide historical perspectives that even further enhance the understanding of context.

It is the combination of these two key data streams that permits effective location-aware and preference-aware adaptation by software to effectuate a context-aware action in the vicinity of the user.

B. Logic and Physical Layers

Logic and Physical Layers combine knowledge management, Semantic Web, workflows, self-adaptivity and agent-based techniques for managing distributed domain and operational knowledge, as well as for efficiently defining, executing, storing and publishing self-adaptive ubiquitous services as semantic-driven workflows. We remand to [3] for the details. Here we briefly recall the main features of such a framework, instantiated for the AAL domain.

Physical Layer: At this level, the Application Layer objects are represented as software components (i.e., agents executed in an active middleware) representing sensors (smoke, temperature, door status, location of the user, and so on), actuators (speech synthesizer, device regulators, emergency calls, and so on) and services and interacting with each other.

An *Agent-based middleware*[2], implementing a migrating workflow model [5], provides the run-time environment for executing services as mobile and distributed code. In particular, it enables, transparently to users, the interaction with the external resources, i.e., invoked applications, and the agent migration to different sites.

Logic Layer: It pivots on a *Conceptual Model* aiming at solving the semantic heterogeneity of all the (Application Layer) resources and activities, as well as at allowing the realization of well-formed, ubiquitous and self-adaptive services from (semantically) heterogeneous, distributed and constantly updated resources and activities.

A Semantic Knowledge Management System (SKMS) allows to describe and annotate in a multi-level conceptual model any (Application Layer) environmental/emotional data (in *Human Ontology* and *Environment Ontology*) and activities (in *Task Ontology*).

[2]Due to the lack of space, middleware architecture is not discussed here and we refer to [4] for further details.

It aims at solving, in a transparent and automatic way, factors like semantic (meaning) and computational (interface of invocation) heterogeneity, level of awareness, physical distribution of resources, etc.

In particular, the input data heterogeneity is solved introducing an abstract concept of *sensor*. According to its vision, the general concept of entity is used to identify any kind of object either physical, artifact or abstract:

- Physical and artifact entities (e.g., people, smartphones, domestic appliances, air conditioning, automatic doors, and so on) play the role of pervasive sensors, that is, they are equipped with a traditional device permitting identification and/or transmission of signals (e.g., RFId, GPS, Wi-Fi, and so on);
- Abstract entities, including social networking activities such as Facebook and Skype, act as social sensors, gathering information about the way the user is feeling.

The Semantic Workflow Management System (SWMS) is the component which allows to edit services as semantic-driven personalized workflows, to monitor their execution, to conceptualize them as a procedural knowledge and to publish them in the form of SaaS.

A Web-based graphical interface enables to edit healthcare services as XPDL[6] workflow specifications, simply dragging-and-dropping resources and activities from the Conceptual Model. It also enables the execution of edited and already published services, the monitoring of their execution state and the management of the produced results.

An *XPDL compiler* translates workflow specifications into interactive component-based specifications and generates the code to be executed on the agent-based middleware. The associated workflow specification is the coordination model that describes how the generated agents cooperate to reach a particular goal, when executed on the agent middleware.

The operator signature available in the SWMS has been defined with the purpose to be a language-independent kernel. As a consequence, any workflow specification can be also automatically conceptualized according to a corresponding BPMN (Business Process Modeling Notation) [7] Ontology kernel and stored as a SaaS concept in the Task Ontology.

A healthcare expert can edit a workflow, selecting the appropriate and involved environment, human and task concepts, associate specific goals and store them. Service exceptions are managed at two (cooperating) levels: either at the editing level - where the semantic layer naturally allows exceptions to be handled as explicit and user-defined workflow activities - or at the middleware level - where a special agent is devoted to handle exceptions in according to different behaviors (invocation of equivalent activities, activity stop/pause/resume etc.).

III. Techniques and methods for self-adaptive services

Self-adaptive planning is a vital aspect of self-adaptive systems. Self-adaptive systems should autonomously adapt at run time to changes in their operational environment, guided by the goals assigned by their stakeholders [8].

Following Ganek and Corbi [9], we define self-adaptive services as services that can automatically take the correct actions based on their knowledge of what is happening in the environment, driven by the events and activities as well as by the goals the stakeholders (healthcare domain experts) assigned to them. In other words, self-adaptive services can modify its behaviour in response to changes in its environment to better meet users' requirements [10].

From an architectural viewpoint, a self-adaptive service needs to implement some form of built-in feedback loop - by collecting information, analysing it, deciding on further and better actions to reach the goal - for tuning itself according to the user needs.

Continuous interaction, collecting and conceptualization of information, detailed user's status and appropriate user's profiling are just the key issues to address the needs of elderly users at home, as well as experts at the healthcare centers, relatives or friends somewhere by mobile devices or Web interfaces, that can benefit to other appliances to make smart decisions making and to provide/exploit services highly aware of their context of use and self-adaptive accordingly.

Applying formal languages such as XPDL, PDDL (Planning Domain Definition language) [11] and BPMN, enriched with semantics given by the Conceptual Model (i.e., Human, Environment and Task Ontology), agents can infer new knowledge useful to personalize a healthcare service. Figure 3 (a) describes the self-adaptive planning approach as a business process.

In the following, the main activities in Figure 3 (a) are described:

- *Identifying (user) needs*: this activity extracts from the Conceptual Model the user needs reasoning over the knowledge base (i.e., T-box and A-box);
- *Context-awareness*: this activity allows to contextualize the user's profile in a specific context looking at social and pervasive sensor input data;
- *Goal*: this activity adapts a generic (target) goal to a specific user's profile according to its needs;
- *Adaptive planning*: this activity generates a tailored personal healthcare service specified as a workflow. In this task we use NuPDDL [12], semantically annotated with input data and activities, and a BPM solver for determining the personalized healthcare service (see Fig.3 (b)).
- *Service Brokering*: this activity determines what services, platforms, infrastructures, contents are needed for

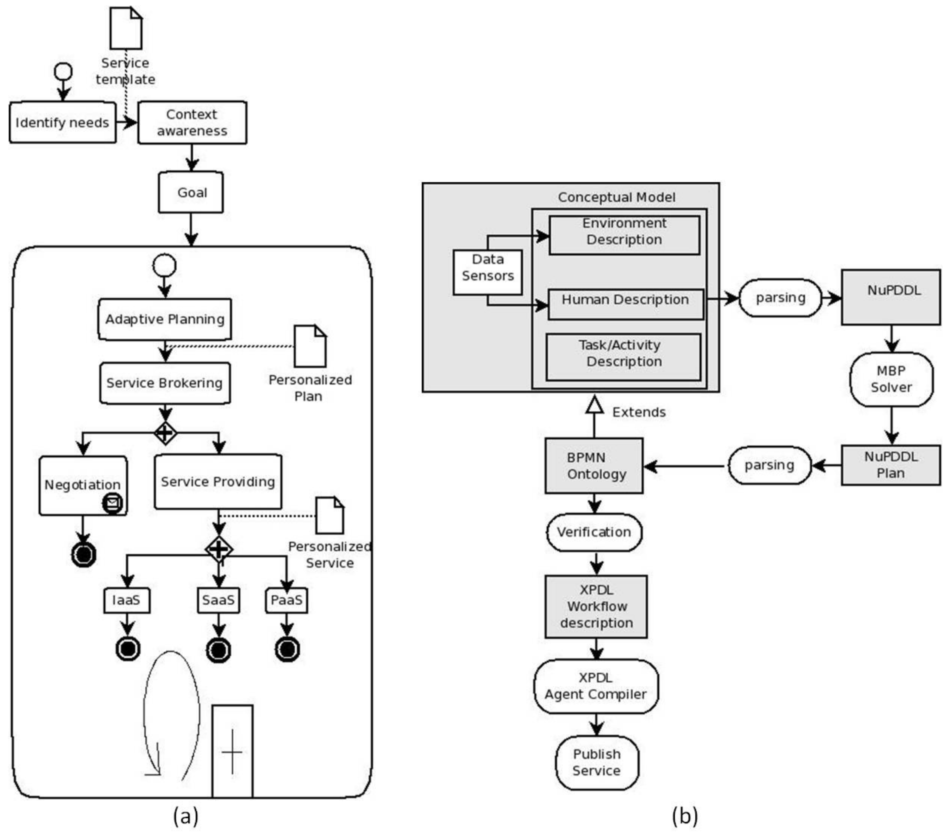

Figure 3. (a) High level Business Process approach to self-adaptive services; (b) Planning approach of a personalized self-adaptive service.

reaching the goal;

- *Service Providing*: this activity provides the final personalized service to the user;
- *Negotiation*: this activity allows the user to tune and further customize the service.

IV. Possible Scenario: Private home with an elderly person with MCI

Elen is 83 years old and lives alone in an apartment in a nice small village. Elen has cognitive impairments; she starts to loose short memory. She is also loosing the ability to walk. She is very worried for her own health condition, but at the same time she wants to maintain her independence. She knows that mild cognitive impairment increases the risk of later developing dementia, including Alzheimer's disease, especially when the main difficulty is with memory. For these reasons she decides to try a technological assistance.

Once technicians have installed the RFID framework, they have to annotate personalized sensors and biosensors w.r.t. Elen's needs. Then, they deploy the Elen's self-adaptive service by specifying the Elen's profile. After that, a set of rules will be specified expressing qualitative and quantitative constraints to the virtual living space w.r.t. Elen's actions and physiological parameters.

For example, *R1*: do not permit Elen to forget taking drugs; *R2*: when Elen drinks water be sure that the temperature is less than 10; *R3*: do not allow that Elen remains without drugs; *R4*: regulate the amount of drugs that Elen must take by reasoning over her physiological parameters.

The self-adaptive service will monitor her physiological parameters in order to suggest proper drugs to be taken and, especially, it will prevent her from doing actions (take the wrong medicine or the wrong amount of medicine or the wrong combination) arising dangerous situations. During Elen's every-day life, will act as a caregiver watching.

While she lives, the system will reason over her healthy status using the rules it has been given and inferring new ones. It will predict dangerous situations and, through actuators, will regulate the arising unwanted configuration by creating events that constraint the environment (drug dispenser) to adapt Elen's needs.

V. Conclusion

This paper suggests a methodological approach for designing self-adaptive ubiquitous and personalized services in the healthcare domain. Following Ganek and Corbi [9], we have defined self-adaptive services as services that can automatically take the correct actions based on their knowl-

 ISBN: 978-1-61208-171-7

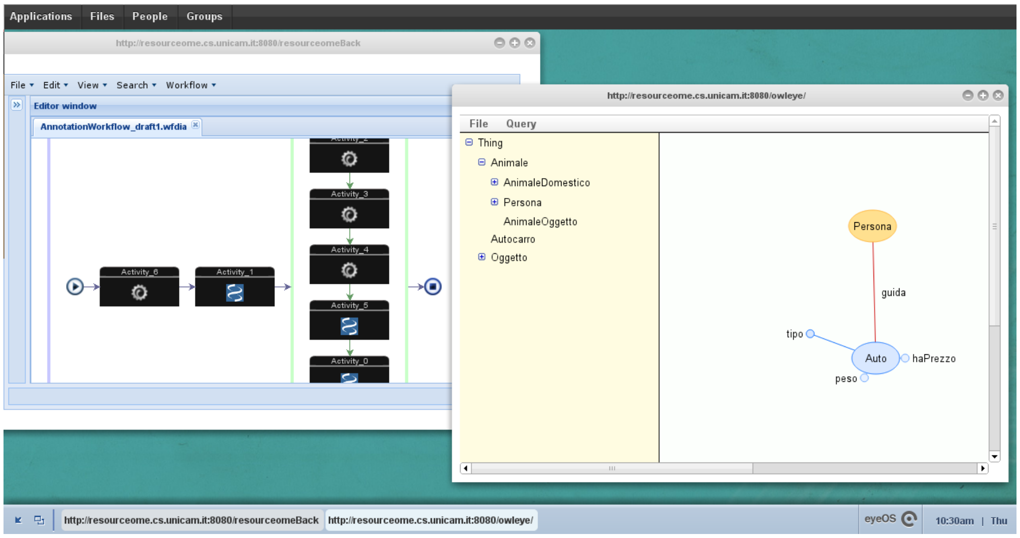

Figure 4. The skeleton of the Elen's service, edited by the SWMS graphical interface.

edge of what is happening in the environment, driven by the events, the activities and the goals the stakeholders assigned to them.

It is worth noting that such an approach can be extended without effort to any domain, simply conceptualizing it in a proper way and instantiating the Conceptual Model with the specific ontologies.

Currently, our approach is partially implemented and is being used in the healthcare domain for the development of a drug dispensary service for people with mild cognitive impairment (MCI). What should be done in a near future is to experiment the system in a real home.

ACKNOWLEDGMENT

This research is partly supported by the JADE project *Joining innovative Approaches for the integration and Development of transnational knowledge of clusters policies related to independent of Elderly* (FP7-Capacities, 2011-2013).

REFERENCES

[1] M. Weiser, "Whatever happened to the next-generation internet?" *Commun. ACM*, vol. 44, no. 9, pp. 61–68, 2001.

[2] D. Cacciagrano, F. Corradini, and R. Culmone, "Resourcehome: An rfid-based architecture and a flexible model for ambient intelligence," in *Proceedings of the 2010 Fifth International Conference on Systems*, ser. ICONS '10. Washington, DC, USA: IEEE Computer Society, 2010, pp. 6–11. [Online]. Available: http://dx.doi.org/10.1109/ICONS.2010.9

[3] D. Cacciagrano, F. Corradini, E. Merelli, L. Vito, and G. Romiti, "Resourceome: a multilevel model and a Semantic Web tool for managing domain and operational knowledge," in *The Third International Conference on Advances in Semantic Processing (SEMAPRO 2009)*, P. Dini, J. Hendler, and J. Noll, Eds. IEEE Computer Society, 2009.

[4] F. Corradini and E. Merelli, "Hermes: Agent-Based Middleware for Mobile Computing," in *SFM*, 2005, pp. 234–270.

[5] F. Corradini, R. Culmone, and M. R. D. Berardini, "Code mobility for pervasive computing," in *WETICE*. IEEE Computer Society, 2004, pp. 431–432.

[6] "Xml process definition language." [Online]. Available: http://xml.coverpages.org/XPDL20010522.pdf

[7] "Business process modeling notation." [Online]. Available: http://www.bpmn.org

[8] N. Khakpour, S. Jalili, C. L. Talcott, M. Sirjani, and M. R. Mousavi, "Pobsam: Policy-based managing of actors in self-adaptive systems," *Electr. Notes Theor. Comput. Sci.*, vol. 263, pp. 129–143, 2010.

[9] A. G. Ganek and T. A. Corsi, "The dawning of the autonomic computing era," *IBM Systems Journal*, vol. 42, no. 1, pp. 5–18, 2003.

[10] A. Lapouchnian, Y. Yu, S. Liaskos, and J. Mylopoulos, "Requirements-driven design of autonomic application software." *In H. Erdogmus, E. Stroulia, and D. A. Stewart, editors, CASCON, IBM*, pp. 80–94, 2006.

[11] D. Mcdermott, M. Ghallab, A. Howe, C. Knoblock, A. Ram, M. Veloso, D. Weld, and D. Wilkins, "PDDL - The Planning Domain Definition Language," Tech. Rep., 1998. [Online]. Available: http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.37.212

[12] "NuPDDL." [Online]. Available: http://mbp.fbk.eu/NuPDDL.html

 ISBN: 978-1-61208-171-7