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SOPRANO – An extensible, open AAL platform for elderly people based on semantical contracts [1]

Peter Wolf[2] and **Andreas Schmidt**[3] and **Michael Klein**[4]

Abstract. Several initiatives have shown the potentials of applying AI techniques to ambient intelligence in general and ambient assisted living in particular. While these systems succeed in adding "intelligence" to systems, they do not provide the extensibility and openness of products ready for the market. In this paper, we present the SOPRANO approach, which is based on a combination of ontology-based techniques and a service-oriented device architecture. In this approach, we focus on separating different aspects of the system like sensors & actuators, context information, and system behaviour, and provide a framework that clearly defines contracts for different solution contributors utilising semantic technologies.

1 Introduction

The SOPRANO project[5] aims at building an *ambient assisted living* (AAL) system for older people that is both based on an extensible and open platform and on innovative technologies. It shall enable the provision of flexible and personalised IT services to help elderly people with functional impairments maximising their independence and help them retaining their dignity. Concrete examples of such services provide functionality that improves the situation with respect to medication reminding, home automation, coping with increasing frailty, home safety and security, activity monitoring, keeping healthy and active, coping with cognitive ageing and forgetfulness, combating social isolation, and countering boredom. With this flexibility, SOPRANO can also produce affordable solutions, each of them tailored to individual needs, but based on a set of components glued together by an intelligent infrastructure. Given the complexity of AAL scenarios, this involves different stakeholders, characterised by different goals, intentions and levels of knowledge and typically represented by different companies[6]:

- *Device technology providers* develop innovative hardware sensors that can be useful in various AAL environments and are not specifically target to be supportive for elderly people. Examples are sensors that detect the location, the posture or the health status of a person or sensors that provide information about the situation of appliances in the house. Experts of this group typically have a strong background in electrical engineering.
- *Software developers* develop algorithms which use sensor input to derive new information that could be interesting to better support elderly people. Examples for that are data mining algorithms that derive indicators for deceases from motion or nutrition pattern or reasoning algorithms that fuse data from different sensors to obtain higher-level information. Experts of this group typically have a strong background in computer science.
- *Telecare solution engineers* create suggestions for the behaviour of an AAL system for elderly. These recommendations arise from their general knowledge on problems of elderly people and are not targeted to one specific assisted person (AP). An example of such a system behaviour template is a suggestion template for the case of forgetfulness. These suggestions could include reminders and warnings about devices that are still running when the AP leaves the house. Application developer who program applications tailored to the assisted person and thereby incorporate domain knowledge can also be incorporated in this group. In general, experts in this group have expertise in telecare situations and the care market as a whole.
- *Care providers* are responsible for one or more specific APs. As they know the concrete situations and needs of their APs very well, they are able to personalise the system to optimally support the respective AP in his or her daily life. For example, in case of forgetfulness of the AP, the care provider can configure the system to monitor the state of electrical devices in the kitchen and living room. Note that also family members or neighbours can be carers ("informal carers") or the AP can be his or her own carer ("self carer"). The carers have typically a non-technical background. Other service providers with little or no technical know-how can be included in this group as well.

Like in other markets, an AAL system for the elderly can only become successful if it operates on an open and extensible platform where a large number of organisations from different areas can contribute in way that (a) optimally utilises their expertise and capabilities and (b) is independent of other contributions. This provides the advantage that the innovation process and also value chain can be distributed over different organisations and is not centralised at one place. Of course, such an open platform needs one organisation that provides the platform for the partners.

In the following paper, we will give a short overview why existing AAL systems (especially for the elderly) do not optimally support these different stakeholders (Section 2). In Section 3, we then present SOPRANO as an open and extensible AAL platform especially for the elderly that uses a common ontology, contracts for the different stakeholders and a system engine to achieve this goal. Finally, in Section 4, we summarise the paper and give an outlook to possibilities of further development.

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[2] FZI Research Center for Information Technologies, Karlsruhe, Germany, wolf@fzi.de
[3] FZI Research Center for Information Technologies, Karlsruhe, Germany, andreas.schmidt@fzi.de
[4] CAS Software AG, Karlsruhe, Germany, michael.klein@cas.de
[5] www.soprano-ip.org
[6] Some stakeholders, however, do not directly influence the behaviour of an AAL solution and are not considered here. This includes, for instance, insurance and maintenance companies.

2 Related Work

If we analyse existing AAL systems (in general, but also for the elderly), we discover that they do not offer sufficient means to be adapted by the different stakeholders described above. Often, these systems are too monolithic and thus are hardly upgradeable. In other cases, the possibilities to extend the system are not focused on the different roles; or unclear dependencies between the different modules hamper the stakeholder's concentration on their own expertise and capabilities, which in turn hampers the provision of innovative solutions and novel contribution to the systems.

In the following, three classes of AAL systems together with their drawbacks are presented and prototypical system examples are given:

- *Home automation.* Such systems are typically developed mainly by sensor providers, software engineers and network experts. The specific input from domain experts (such as telecare solutions experts and care providers) is missing. Thus, the specific requirements of older people are not targeted or often even not approachable in a way that a non-technician is able to understand. Examples for research projects in this area are the *INHOME project* [16] which focuses on the personalised management of audio-vision content as well as the *EASY-LINE+ project* [11] which concentrates on intelligent white goods.
- *Agent-based AAL systems.* Such systems are characterised by autonomously acting devices (or "agents") that have their own intelligence and the sum of all these agents leads to the overall (emergent) intelligence of the system. Extending the system by new agents is possible, but the development of a new agent is a conjoint effort of all four aforementioned groups, since the underlying infrastructure is not tailored to utilise various degrees of technical and domain knowledge. An example for a research project in this area is the *DynAMITE project* [10] which is based on SodaPop, an infrastructure for self-organising environments [3] offering the possibility to group components and to route the communication between the different component groups with public conflict resolution strategies. Project with similar approaches are the *PERSONA project* [20] which will be based on a bus architecture to combine a set of intelligent devices and the *AMIGO project* [9] that has a service oriented architecture with service composition strategies. Though, each service needs to implement these strategies on its own. Further projects in this area are the *MONAMI* [18], *SENSACTION-AAL* [21] and *I-Living project* [15].
- *Monolithic intelligent systems.* Systems are characterised by a central and opaque "brain" that provides the intelligence for all attached devices. These systems typically rely on highly-customized algorithms based on logical reasoning. It is very hard to extend these systems at all, as separate components are missing. Research projects from this area are the *EMBASSI project* [12] that brings intelligence to the living room, automobiles and terminal systems, the *MAP project* [17] that operates in office scenarios and the *SmartKom project* [23] that is specialised on mobile situations. A newer approach is the European funded *EMERGE* project [13] that develops a prototypical solution for treating emergencies with a stepwise assistance.

Until now, only very few solutions have reached a high market attention. We believe that this is due to the fact that the underlying platform does not support the different stakeholders appropriately and thus hampers the innovation process. To solve this problem, various new projects have been started, e.g. *ALADIN* [8], *OLDES* [19], *ENABLE* [14] and *SHARE-IT* [22]. SOPRANO however is characterised by a much stronger market-orientation – its results will be transformed into a product for the mass market afterwards. To ensure a sustainable success on the market, SOPRANO will allow for integrating the solutions of different providers in an open manner and thus leads to an optimally targeted, constantly improving and nevertheless affordable solution.

In the next section, we will explain the idea of SOPRANO and show how clearly defined semantic contracts help to make SOPRANO a reference platform for open and extensible AAL systems specifically targeted at the domain of elderly people.

3 Our Approach

Within SOPRANO, we have tackled the requirements and needs presented in the previous chapter, i.e. providing a system that utilises capabilities and expertise of the described stakeholders, with an open platform approach based on a combination of semantic-enabled technologies and service-orientation. The SOPRANO infrastructure will provide strictly predefined contract-based interfaces for each of the above presented stakeholders based on a formal ontology. These contracts contain semantically rich descriptions of the context data that can be accessed and/or contributed. Furthermore, the effects of newly contributed data or of configuration issues are clearly restricted to a certain, well-defined aspect of the system, minimizing unintended side-effects.

Figure 1 outlines the main idea of our solution. On the left hand side, the basic architecture of the provided infrastructure is presented. The shown components, namely the *semantic service layer*, the *context manager*, the *composer* and the *procedural manager* form the basis of the common framework that can be extended. A more detailed description of their functionality is given in [4]. On the right-hand side, the position of the different groups introduced in Section 1 indicates the system component they have to communicate with. The SOPRANO ontology constitutes the semantic glue between the framework components and the foundation for the interface contracts.

The provision of contract-based independent interfaces tailored to the know-how and requirements of the above mentioned stakeholders will be achieved by providing three basic system components:

- *The SOPRANO ontology.* The ontology acts as a mediating artefact between the different system components by providing a common interconnected vocabulary on different layers of abstraction. The lowest level provides a vocabulary for the semantic description of services. On top of that, the low-level ontology describes the state of all supported devices. Finally, the high-level ontology defines a vocabulary centred on the environment of the AP. The vocabulary is centred on the notion of state (the AP has a certain state, e.g a location state, health state etc.) which allows for the definition of context features as states, situation changes as state changes, and goals, i.e. effects of workflows or actions, as desired states. The actual system ontlogy is modelled using RDFS-like semantics based on the approach presented by SCHMIDT [24]. Figure 2 shows a simplified version of the SOPRANO ontology.
- *The service-oriented infrastructure.* As outlined above, the SOPRANO platform needs to be highly extensible. On a basic level this requirement calls for the use of a service-oriented infrastructure where new system components can easily be added and exchanged. Since the *open-service gateway initiative* (OSGi) supports operational reliability and enables remote provisioning it suits the proposed requirements (for an overview on advantages

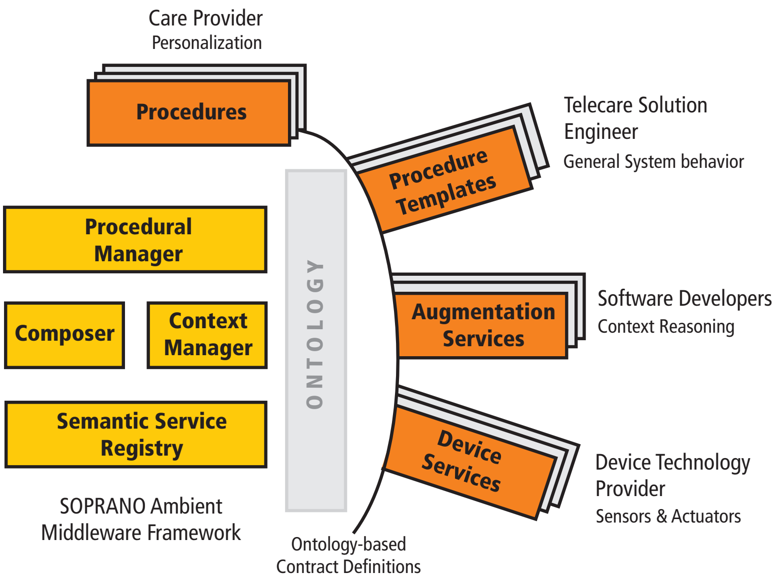

Figure 1. Indentified stakeholders in relation to the SOPRANO ambient middleware framework.

of OSGi in smart homes see [6]). Therefore, the technological platform for services will depend on the open-source equinox implementation of the OSGi-framework. This requires that all incorporated software components are integrated as services including services representing sensors and actuators, augmentation agents, and the platform components itself (see Figure 1). As the OSGi-framework supports all inter-component communication and the complete service lifecycle, the OSGi service registry constitutes the most basic layer of the architecture.

- *The SOPRANO Ambient Middleware (SAM [4]).* The SOPRANO middleware (see components on the left-hand side in Fig. 1) is implemented on top of the OSGi service layer. Based on semantic service descriptions as outlined in [5], it facilitates semantic service matchmaking (Semantic Service Registry), access to and management of context data (Context Manager), based on techniques described in [25], automatic context-aware mapping of actions described on a higher semantic level to the actual incorporated actuators (Composer), and a workflow management system (Procedural Manager).

In the following, we will analyse the contracts for the 4 different groups indicated in Chapter 1 and their interaction with the SOPRANO infrastructure.

3.1 Device technology provider

As explained in Chapter 1, the sensors and actuators are implemented, supported and maintained by the device technology provider. To communicate with the SOPRANO platform the incorporated sensors and actuators must be installed as OSGi bundles. Furthermore, these device services must provide or handle data in conformance to the vocabulary defined within SOPRANO's low-level ontology, i.e., we expect semantically-enriched sensor services. This compliance towards a strictly defined vocabulary and formalism clearly indicates that the detected context information is processable by the system. Furthermore, all higher-level services that operate on this low-level context data are provided with a semantic description of the data they can possibly expect (low-level ontology) and deal with it.

If an improved sensor is plugged into the system, the sensor developer can simply remove the old one and register the newer one for sensing the same context-features. All higher-level services do not have to deal with the exchange but can simply enjoy the better detection quality of this particular feature. The sensor developer, in turn, does not have to deal with using the sensor information as part of the overall system behaviour.

On the other hand, the immediate effects of actuators are also modelled within the low-level ontology. Newly incorporated actuators have to register themselves within the semantic service registry. If a certain desired state (defined on a higher-level) needs to be achieved, semantic matchmaking algorithms automatically match the desired state description to the low-level actuator description and execute the actuator that fits best.

Table 1. Contract with device technology provider

Input:	Interface to the semantic service registry, semantic description of data
Job:	Integration of OSGi and ontology compliant devices
Output:	Low-level context data

3.2 Software developer

On a next level, within a typical AAL solution, software developers aim at providing innovative techniques for aggregating, combining, or augmenting context information. These techniques are applied to achieve a consistent more reliable and semantically rich description of the user context [7]. As these tasks heavily rely on high-performance and reliability, the expertise provided by software engineers is needed to deliver appropriate solutions. The contract states that these so-called augmentation agents, installed as OSGi-bundles, can access the context information through a well-defined API that provides access to context manager functionalities like querying and writing of context data. This implements the blackboard architectural pattern [2], based on the ontology-based context management approach in [25] that allows for dealing with imperfection in a controlled way. Their main goal is to use the data stored in accordance to the low-level ontology and return data in conformance to the high-level ontology. The high-level ontology compromises a vocabulary tailored to the domain of elderly people that is used for situation detection and context-aware behavioural adaptation (see Fig. 2).

On the same level but vice-versa top-down agents can be implemented to break down high-level actions, expressed within in the high-level ontology through desired states, into concrete service invocations based on actuators modelled within the low-level ontology. This process of concretisation takes into consideration various context-features and preferences of the AP. This tailors the action towards the actual situation and needs of the AP and exhibit an intelligent situation-dependent system behaviour.

New agents can easily be plugged in and extract additional information out of the provided data and/or in return achieve a better computation of high-level context. In contrast to other approaches, this contract does not prescribe any context reasoning formalism, e.g., based on description logics and specific rule language. Rather, this approach allows for different techniques, which includes both logic-based and mining-based services (e.g., for activity pattern detection).

Similarly, new top-down agents can achieve more intelligent system behaviour by applying more sophisticated reasoning approaches based on the ontology or incorporation of external sources. In this case, the high-level desired state description as starting point and the lower level actuator description as an endpoint of an execution will remain, but the intelligence or context-awareness in between is adaptable.

Table 2. Contract with software developer

Input:	Interface to the context mananger, context data, semantic description of data
Job:	Application of data-mining and AI techniques
Output:	High-level context data

3.3 Telecare solution engineer

The telecare solution engineer aims at delivering an AAL solution that is tailored towards the customer group of older people. This includes the possibility of personalising to the various needs of the AP [1] and, in order to reduce costs, aims at an easy configurable solution–even by people with a non-technical background who constitute the immediate social environment of the AP. This results in a solution in which as much domain knowledge of the telecare solution engineer is incorporated but with most of the personalisation left to the care provider as possible.

This personalisation mainly includes procedural knowledge about the system behaviour (in contrast to the state information provided by the context manager) so that we have a clear separation of these aspects. The system behaviour description is tackled using a formalism comparable to business process templates [26]. Technically, a procedural template does not provide any runtime functionality but restricts the scope that is supported via the system. The formalism used is based on *Web Services Business Process Execution Language* (BPEL) modelling language with omissions and selectable alternative constructs. Care professionals can instantiate these templates by replacing the omissions and choosing from the provided alternatives.

Besides the BPEL constructs for conditions, repetitions and local data storage–events, defined as high-level context changes, can be used to specify when a system should execute such a procedure. The context manager triggers events in response to high-level context changes but only if one or more procedures are registered for this specific event. The reactions to these events are also modelled within the high-level ontology as desired states that are to be achieved.

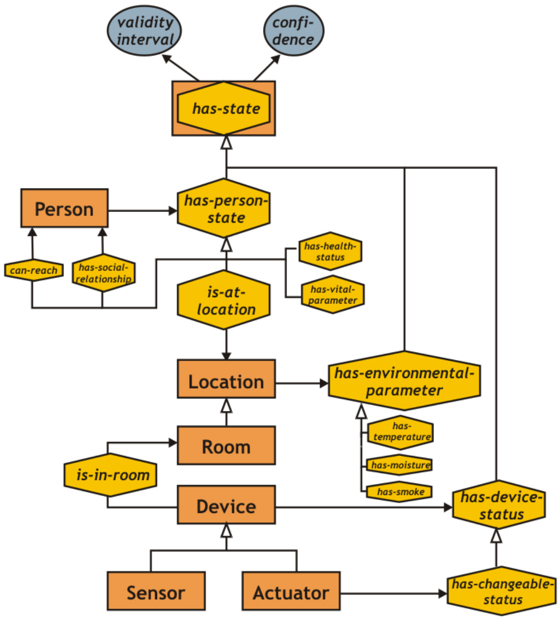

Figure 2. Extract of the SOPRANO ontology.

In combination, a template specifies the situations of the AP that the system can possibly address and gives an outline of appropriate reactions that need to be further personalised to become an executable workflow. Therefore, a procedure template outlines the workflows or use cases that are supported by a specific SOPRANO solution. An API and GUI for managing procedure templates and procedures is provided by the procedural manager on top of the SAM infrastructure (see Fig. 1).

Table 3. Contract with telecare solution engineer

Input:	GUI for designing procedural templates, set of events/actions, BPEL-constructs
Job:	Identifying possible use cases, designing of procedure templates
Output:	Impersonalised templates that outline system behaviour

3.4 Care provider

On the topmost level the care provider is able to easily personalise the system to the conditions at a specific home. Within SOPRANO, as the process of template instantiation is clearly defined, described and supported via a graphical user interface, this is even accomplishable by non-technicians. The idea is, that professional carers, call centre employees who are in direct contact with the assisted person, informal carers or even the AP as "self carer" are able to incorporate their specific knowledge about the AP's immediate environment. This knowledge can be directly applied into the procedures to assure certain very important and critical behavioural aspects; or is instantiated into the high-level ontology, e.g. in form of preferences. So, later on, the system can automatically (see top-down agents) tailor the system's actions to the needs, preferences and situation of the user by exploiting the high-level context.

Table 4. Contract with care provider

Input:	GUI for system personalisation
Job:	Instantiate procedure templates, add context data
Output:	Executable procedures, personal contextual information

4 Conclusion

In this paper we presented the SOPRANO approach to engineering affordable AAL solutions. The key idea of SOPRANO is to provide an open platform as the core for a solution ecology that allows for a flexible and personalisable solution. Such an ecology comprises different stakeholders in the domain of AAL systems for elderly people that can contribute their knowledge independently (on an open market), using an interface that is tailored to their specific needs and requirements. As stakeholder we identified the sensor technology provider, the software developer, the telecare solution engineer and the care provider. The objectives of these stakeholders are distributed on various areas ranging from very technical areas like engineering and software development up to the health care domain.

The solution presented in this paper is based on a ontology-centred platform that provides contract-based strictly predefined interfaces. An extension of system functionality is thereby possible with less effort than within in the comparable solutions presented in Chapter 2 which promises more sustainability of such an AAL solution.

The SOPRANO platform will be validated and evaluated with existing sensor and actuator technology in large-scale trials in 300 existing homes in four European countries. Further trials in living labs (smart homes) will allow for testing the approach with cutting edge technology.

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