# PIPS: An Integrated Environment for Health Care Delivery and Healthy Lifestyle Support

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**Abstract.** In this paper we introduce the PIPS System, an integrated environment for the delivery of health care and support for a healthy lifestyle, developed under the European Commission Framework 6 call. In order to accommodate in the system many types of users, with different roles and needs, and many devices a multi-agent system approach has been selected as the natural choice for the design of the core system component, the decision support layer. We will present this exercise, by describing the resultant architecture of the system, and two application scenarios, in the area of chronic diseases management and healthy food habits promotion, that demonstrate the usefulness of the multi-agent approach.

## 1 Introduction

PIPS (Personalised Information Platform for Health and Life Services) is an e-Health Integrated project funded by the European Commission under the Framework 6 call, that aims to create novel healthcare delivery models by building an environment for Health and Knowledge Services Support.

This environment integrates different technologies in order to enable healthcare professionals to get access to relevant, updated medical knowledge, and European citizens to choose healthier lifestyles. The project aims to bring together healthcare suppliers, citizens, public organizations, food/drug industry and services, researchers, and health related policy makers in order to create a dynamic knowledge environment. This dynamic environment builds on traditional and new approaches for handling knowledge from current medical practice, evidence based medicine, and disparate knowledge sources from health/nutrition domains.

The philosophy underlying PIPS is to provide an integrated environment that enables the interaction of different types of users with conventional computers as well as small, and ubiquitous devices, such as mobile phones and medical devices, at the aim to provide them with personalised advices. The PIPS platform combines a number of technologies in order to generate these personalised advices, such as software agents, intelligent decision making, natural language generation and knowledge management.

In the PIPS project, major attention is dedicated to the issue of promoting compliance to the medical advice. The PIPS philosophy, in accordance with recent research in health promotion, is that the patient/citizen has to have the locus of control of his own behavior, in order for the advice to be completely understood and put into practice. Nowadays, the adherence to chronic disease treatments, such as hypertension, diabetes, asma, AIDS, depression, and celiac disease, only reaches in average 50%. Just half of the patients suffering these diseases take suitably the prescribed drugs, and the other half takes them unsuitably or does not take them at all [11]. Besides the marked deterioration in the quality of life that a complication in these diseases may cause, in the US, for instance, it is known that a lack of adherence to the treatment causes almost 125,000 deaths a year and approximately 10% of the hospital admissions are due to this fact. Likewise, each year, the no-adherence entail 100,000 million dollars in direct costs to the health system and 50,000 million dollars in indirect costs due to labor absenteeism [13].

By educating and informing the patient, one can reduce the risk of complications and increase the patients comfort level and response to therapy. Informed patients with realistic expectations are more likely to be satisfied with the therapy and in turn, positively influence their own therapy experience. However, the goal of PIPS is to concentrate also on a prevention phase, where citizens have to be informed on best practices and educated on the best ways to improve their health and life.

The Decision Support System (DSS) addresses the objective detailed above by creating the main framework for the PIPS users to interact with the system, and receive all the necessary information, support and advice. The vast amount of ever changing information and dynamic interaction between components means that implementing such a system using standard software engineering practices would be difficult. Agent technologies offer us an abstraction mechanism that is well suited to such systems, and for this reason, we have implemented the DSS as a multi-agent system.

In this paper we are going to present the agent-based architecture that has been employed to realize such component of the PIPS System. The paper is organized as follows: we firstly provide an overview of the overall PIPS platform architecture; then we focus on the DSS layer and describe in details the agent framework, its design, interaction paradigm, etc.; the third section is dedicated to the description of two application scenario in which the proposed architecture is employed to provide added-value services to the user; finally we present our conclusions and future steps .

## 2 PIPS Overall Architecture

Figure 1 aims at providing a comprehensive view of the functional blocks that compose the PIPS System in order to identify the main PIPS component. As "Core System" we identify all the server side parts of PIPS, that is all the data and applications that are not directly

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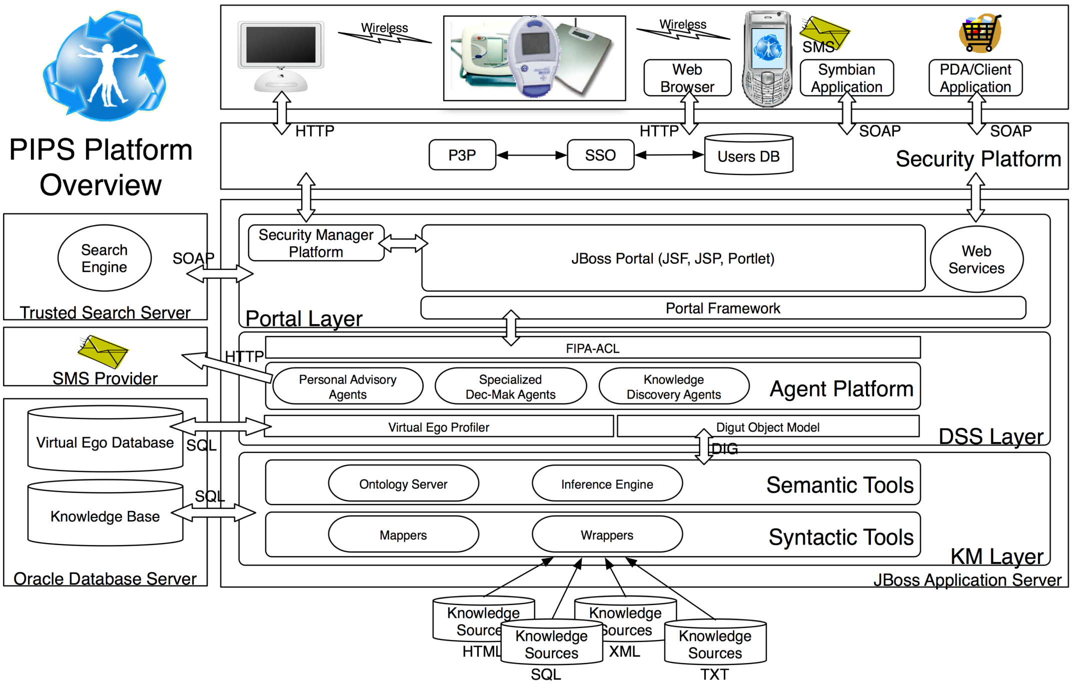


**Figure 1.** PIPS Platform Overall Architecture

related to devices and networks. PIPS consists of the following modules:

- PIPS System Portal: the multi-modal and multi-channell user interface to the PIPS System;
- Trust and Security (T&S) infrastructure, including the T&S management at the Portal level along with the Knowledge Management (KM) Trust Mechanism at the Data Source level;
- Decision Support System (DSS, center of above picture), including the agents system (Personal Advisory, Specialized Decision Making and Knowledge Discovery agents) and the Virtual Ego profiler that maps data stored on the Virtual Ego Database;
- Virtual Ego (VE), representation of the user in the system. It holds a dynamic profile of the user that includes data regarding nutrition, health, anthropometric, habits, preferences, physical activity, and all the other possible dimensions that are involved in the PIPS scenarios;
- Knowledge Management System (lower-right corner of above picture), including the Semantic Tools (Semantic Engine, Ontology Server for Health & Nutrition and its related instances stored in the Knowledge Base) and the Syntactic Tools (Mappers and Wrappers of Knowledge Sources);

Additional details on the PIPS system can be found in [7] for the aspects related to trust management, in [6], [4] and [5] for the design of the KaSeA Semantic Engine, in [9] for some of the ontological aspects, in [14] for the nutritional issues covered by the project, in [10] and [3] for the motivational and personalization aspects.

## 3 PIPS Agent Architecture

The decision-making process in PIPS is seen as a series of interactions between the user and the Knowledge Management System. This view is based on the architectural assumption that PIPS is a knowledge-based system that provides context-sensitive personalized health care to a citizen at the point of use.

The multi-agent system that resides within PIPS contributes to form the DSS. The analysis and design of the system was based on the notion of *computational organisations*, whereby the roles played by the agents are modeled on the basis of the roles in real-world organisations. For the high-level analysis and much of the design was guided using the Gaia methodology [20], in which roles are a central concept.

The DSS agents fit into the (mostly) agreed definition of an agent [19]. That is, the DSS agents are:

- *Autonomous*: the DSS agents control their own execution and interaction, and, specifically with the personal advisory agents that handle citizen information, are not required to give out the information that they know;
- *Reactive*: the DSS agents are equipped to react to changes in information and requests;
- *Proactive*: the DSS agents' behavior are directed by goals;
- *Social*: the DSS agents interact and communicate with each other in order to achieve their goals.

Our model is based on real-world health-care systems. Using the Gaia methodology, we derived the roles within the PIPS DSS, which were mapped one-to-one to the agents playing these roles. From now on, therefore, we will discuss roles and agents as if they were the same entity. The agents in PIPS can be divided abstractly into four types:

1. *Interface agents (IA)*: these agents are responsible to handle the communication flow between the user interface (the PIPS portal) and the agent platform;

2. *Personal advisory agents (PA)*: these are the agents that provide personal information to the citizens, such as their diary, or their medical history;
3. *Specialised decision-making agents (SA)*: these are the agents that provide advice or information for the nutritional and medical fields in which the PIPS system specialises, such as diabetes or heart problems;
4. *Knowledge discovery agents (KA)*: these are the agents responsible for locating domain-specific knowledge from the PIPS Knowledge Management System,

One can easily relate the latter three types to roles in a human organisation: the citizen has personal advisory agents, what in many organisations are "personal assistants"; the specialised agents represent the health care specialists and nutritional experts that assess the health and diet of the citizen; and the knowledge discovery agents represent the role of people who would find information about a particular health and nutritional issues, although often this role could be played by the specialists themselves.

The abstract diagram in Figure 2 illustrates this organization and some of the interaction among agents. The existing agents are grouped in rows with respect to their type (i.e. all personal advisory agents are on the second row, the specialized agents are on the third row, etc.).

Such a design also divides the agents into clear categories: the personal advisory agents have knowledge about the citizen only, and acts in the best interest of the citizen within the PIPS system; the specialised agents have process knowledge about the nutritional and medical fields only, and represent no particular stakeholder in the system (although they support many different stakeholders); and finally, the knowledge discovery agents have knowledge about where to find information, and how to construct queries to the PIPS Knowledge Management System. In the PIPS implementation, wherever process and domain knowledge on a particular domain are closely linked, the relevant specialised agents and knowledge discovery agents are coupled into one entity. This prevents redundant knowledge in the DSS, and reflects what is likely to happen in a real-world organisation.

Due to the vast amounts of constantly changing knowledge in the PIPS system, it is unreasonable to assume that an agent has knowledge about even a small amount of the possible requests. For this reason, each agent, whether a personal advisory agent, specialised agent, or knowledge-discovery agent, has knowledge only about a certain subject of the PIPS system. For example, a specialised agent would have knowledge based in a specific area, such as diabetes test. It may know how to help citizens make decisions on what course of action they should take based on their most recent blood-sugar levels.

To help with modularisation, and to reduce the number of agents in the system, processes and domain knowledge are never duplicated among agents — although copies of the same agent may be created if the load is too heavy. This modularised architecture allows new specialised advisory agents to be added to the system without disruption, such that personal advisory agents do not need to have a working knowledge of which specialised agents can perform which tasks.

Each agent in the DSS registers itself upon entry, including in the registration information such as the types of queries that it can address. Each request that is sent to the DSS is annotated with a label that indicates the type of query, and a capable agent is selected to satisfy such request. The *Broker Agent*, one of the Interface agents, is responsible for such selection.

As a general overview of the information flow in the DSS, we return to Figure 2. In this figure, we see that a message, which is annotated with a specialty, sent from a PIPS user comes to a *bridge/broker* agent, whose only two responsibilities include reading messages coming into the system, and locating an agent with specified specialty, and forwarding the message to them. This agent then deals with the request, either by itself, or with the help of other agents in the system.

## 3.1 Personal Advisory Agents

Personal advisory agents are the agents that provide personal information to the citizens, such as their diary, or their medical history. When a request is to be fulfilled for a citizen, it will generally be the responsibility of a personal advisory agent to handle the request, even though these agents do not have information about health or nutrition. In the case that the agent does not have the knowledge to fulfill a request, it must find an agent that does. This is discussed further in Section 3.4.

Personal advisory agents can receive three types of request:

- One-time requests for information or for action. These are generally fulfilled as soon as possible. An example is a message from a specialised agent requesting the glucose levels of a diabetic citizen over the last week, so that the requesting agent can provide nutritional advice to that citizen;
- Requests for periodic information or periodic action. For example, a request to remind the patient to take a medication every evening;
- Requests for information or action when certain conditions arise. For example, whenever a patient's blood sugar levels reach a certain level, recommend the patient to book an appointment with a specialist. This can be considered a maintenance request, in that the system always maintains a certain property by identifying problems before they arise.

Once a request has been received, the personal advisory agent must determine the goals that must be achieved in order to fulfill that request. This task may require the agent to ask for additional information about the citizen if the knowledge it has is not sufficient. It may also require the agent to obtain additional information from specialised agents (most likely specialised for a particular subject) and knowledge discovery agents. The process of locating this knowledge is discussed in further details later in this section.

In our original vision a community of personal advisory agents should be assigned to each user of the system, such that each of these agents deals with the data of only one citizen (thus improving privacy compliant data management). This solution would also allow simple strategies for load distribution among several computational resources. In the first version of the system, however, we have realized a mixed approach where each personal advisory agent is able to deal both with a single user data or with data from all user. Performance tests are being conducted to evaluate the best trade-off between these two alternatives.

## 3.2 Specialised Decision-making Agents

The specialised decision-making agents in the PIPS system are specialised in a certain area of health or nutrition in order to keep them small, and to allow new functionality to be added to the PIPS system by adding an agent with a new specialty.

These agents receive only one type of goal: a one-time request. Specialised agents are not in charge of repeated requests, because

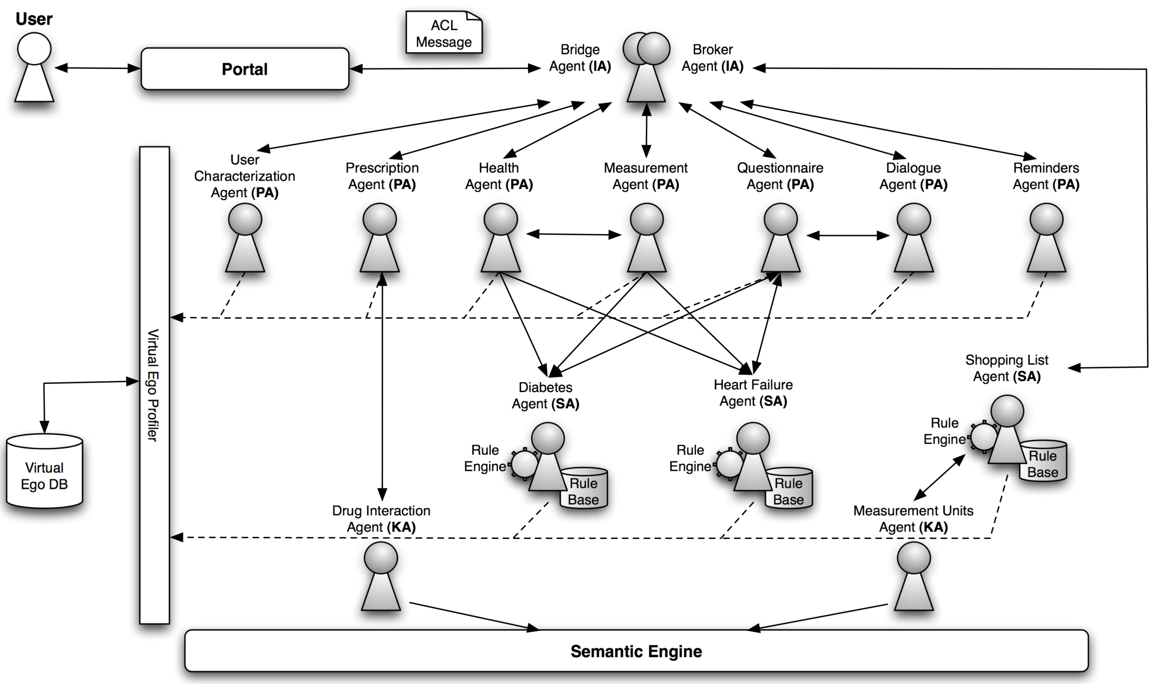


**Figure 2.** PIPS Agent Platform Architecture

these are always related to a citizen, and specialised agents do not represent citizens. Note that a one-time request may involve multiple interactions with the requesting agent, but at the end of such a dialogue, all patient information is removed from the specialised agent's knowledge base. This also helps to maintain the privacy and security policies of the system.

## 3.3 Knowledge-Discovery Agents

Like specialised agents, knowledge discovery agents are specialised in a certain area of health or nutrition. Generally, each specialised agent is coupled with exactly one type of knowledge discovery agent that is specialised in the same area. This may not be the way a human organization would model such a task, but for the PIPS system, this seems the most suitable and straightforward approach.

Knowledge-discovery agents also receive only one-time requests. This is because these agents are responsible only for locating the domain knowledge for the DSS. Knowledge-discovery agents are, in fact, more like components than agents, in that they are not autonomous (they respond to every request) and have no intelligence; however, the agent paradigm gives us a good level of abstraction, and the necessary communication tools for using these agents, so we implement them as such.

## 3.4 Plans and Coordination

Whenever a personal advisory agent has goals, it will continue trying to achieve them if possible. However, often an agent cannot satisfy all of its goals, and even if it can, working on many at one time can become difficult. Therefore, an agent must adopt only a few goals to achieve at any one time. These selected goals are often referred to as intentions. An agent needs a plan for achieving a goal. Typically, a plan is pre-implemented and is executed under certain conditions, however, much research in the artificial intelligence field has been done with respect to agents planning for themselves. In agent systems, and in the PIPS system, planning is not done by the agent, but instead the agent has access to a plan library, from which it can select an appropriate plan to achieve a goal.

A PIPS plan is quite standard, consisting of the following three parts:

- a precondition, which defines the conditions for which the plan is applicable;
- a postcondition, which defines the conditions that will hold after the execution of the plan if the precondition holds before the execution; and
- a body, which is the sequence of actions that are actually executed to achieve the postcondition.

Thus, to select a plan, the agent goes through the plan library, and for each plan in that library, the agent evaluates whether the postcondition of that plan satisfies the goal being evaluated. If and only if it does, then the agent checks that the precondition is satisfied by the current state. If and only if it is, then that plan is adopted as an intention of the agent.

To implement plans, we use a *rule-based* system. Rules are of the form *conditions* ⇒ *consequences*, in which *conditions* are the conditions under which a rule can fire, and *consequences* are the part of the rule that is executed to change data. A *rule engine* is used for rule execution. Each plan is made up of several of these rules. The conditions of the first rule is the precondition of the plan, and the consequences of any rule that is fired during execution is the body of the plan. In the PIPS system, postconditions are often just labels that map to a particular rule to fire, and the agents implicitly know which labels they need to achieve which goals.

If, as part of a plan, an agent requires an activity to be performed or requires some information that is not in its capabilities, it will request this from an agent that does have these capabilities. This process is part of the plan itself. That is, the plan will contain meta-information about how the plan is to be broken up into sub-plans, and how to find an agent that is capable of executing each sub-plan.

Specialised advisory agents have access to a plan library that is specific to its area of specialty, but they are also equipped with plans for resolving conflicts of information in that area. That is, they can detect and resolve the conflicts of information that they receive from sub-plans.

In the present version of the system, the coordination and conflict resolution are implemented as rules, which is feasible because we have only a small set of differentspecialised agents. As the system grows, this approach will not be possible, therefore, an experimental branch of the system is using an ontology-based system for coordination. To do this, we will use the ontology and related rules discussed in [16], which model the process of coordination between agents in a system. Rather than implementing coordination in each plan, this approach allows agents to reason about their own coordination activities, and to enterdialogues in cases of conflict. Such an approach is clearly more scalable and more flexible than the current approach of implementing the coordination and conflict resolution as part of each plan.

## 4 Application Scenario

In the following sections we are going to present how the above architecture has been employed in the PIPS project to realize two different scenarios. The first is focused on supporting chronic patients in their every-day life in tasks like following and adapting a therapy, reacting to abnormal health conditions and interacting with doctors. The second deals with providing support to overweight peoples in being compliant to their diet, helping them with food provisioning and selection.

### 4.1 Clinical Scenario

The PIPS system aims at providing support in daily tasks, both for healthy people and for those suffering of a chronic disease. For chronic patients the main aim is to help improving the compliance to the therapy and provide suggestions for a safer lifestyle. The scenario that we are going to describe presents a typical situation for such patients, specifically in the context of people suffering of heart failure. With the same approach, services for diabetics have also been developed and support for people with serious allergies is being realised.

Our main actor for this scenario will be John Fitzegerald, a 55 year old person who suffered from a myocardial infarction a few years ago and is currently under treatment for an ischemic cardiomyopathy with heart failure (HF) complication. Patients suffering of this syndrome present specific symptoms, like dyspnoea and fatigue, which may limit exercise tolerance, and signs, like fluid retention, which may lead to pulmonary congestion and peripheral edema. Both abnormalities can impair the functional capacity and quality of life of affected individuals.

For this kind of patient it is mandatory to monitor vital signs and the arise of symptoms indicating possible disease accentuation [8]. In particular, monitoring and preventing the accumulation of body fluids allows to prevent respiratory problems, deambulation problems and, in the end, heart exhaustion. Moreover, given that patients suffering from HF usually present other heart related diseases and complications, continuously monitoring these parameters is essential to react promptly and to prevent worsening of the overall patient health condition.

For this reasons, John is following a complex treatment made of different components: he has to take a quite large number of pills daily, he must measure a fixed set of vital signs every morning and he is on a diet.

Therefore, the first support that PIPS provides to John is a reminder service, set with respect to all his prescriptions and integrated with his mobile phone agenda, that reminds him of all actions he must perform on a timely basis. The scenario, in fact, begins with a reminder generated by the PIPS system for the morning vital signs measurement. This reminder is set in John's phone agenda once, i.e. when the a prescription is first created, such that the delivery of the actual reminders does not have impact on the system load. If the patient schedule changes, for instance because the doctor updates the therapy, ansms is sent to the user mobile phone triggering an application that downloads the new schedule and updates the agenda.

In John's case, he must measure his weight, blood pressure and heart rate every day before breakfast. Monitoring these signals daily is fundamental to keep his overall health status controlled and to react properly to any abnormal condition, for instance to accumulation of the body fluids.

For this scenario let's suppose that John was out of town for the weekend, exceeded a little with drinking and forgot to take some of his pills. When he receives the reminder on Monday morning he uses the measurement devices provided by PIPS and collects the needed vital signs. These devices are all connected wirelessly to John's home network and the data collected are immediately sent to the PIPS DSS via a web service. In order to do that an existing platform from Medic4All, one of the PIPS partners, has been integrated in the project, along with a complete set of personal monitoring devices (e.g. scale, blood pressure monitor, portable one-lead ECG, etc.) able to transmit the collected data viabluetooth to a PC or mobile phone [2]. In the DSS, the measurement agent receives the new parameters, stores them in John's VE and notifies all interested agents that new vital signs are available for John. At this point another personal agent, the health agent, reacts to the new parameters, queries the VE for John's disease and then instantiates a new specialised agent to deal with the data (i.e. a new specialised agent is created at run time). At start time, the health agent declares its interested in receiving new vital signs information from the measurement agent sending it FIPA subscription messages. The same approach is followed by the specialized agent as described below.

Once a new specialized agent is activated, as first action it creates a new instance of the rule engine and loads his plan (rule) library. The plan is composed of the following stages:

1. New incoming data are analyzed and out of range values identified. Reference values can be defined by the doctor on a personal basis and are stored in the VE along with all previously collected data. These data are also used to identify abnormal conditions, for instance a weight increase of more than one and half kilos in the previous three days;
2. Additional data, like daily water intake, are looked for in the VE. If they are found and are recent enough they are kept for rules elaboration, otherwise the user will be requested to provide them in the next steps;
3. If any abnormal condition is detected in the user vital signs a ques-

tionnaire is started, in order to collect patient symptoms, find the etiology of his physical condition and retrieve the other information that couldn't be found in the VE. The user is informed of the need to fill the questionnaire both via an sms and with a message on the PIPS Portal. The questionnaire is composed of closed questions and the answers are sent to the specialised agent [5]. Depending on the user answers more questions can be activated, further vital signs measurements requested or other PIPS tools invoked, like a water intake assessment tool;

4. When new vital signs are requested the questionnaire is not suspended, unless no more questions can be planned without knowing the required values. In that case the user is informed that the questionnaire is suspended and invited to take the required measurements. At the same time the specialized agent subscribes to the measurement agent to be notified when that measures come in and, when the user finally takes the measures, the elaboration automatically resumes;
5. When all needed information have been collected, the overall health status of the patient is identified and appropriate advices provided. Advices can be pragmatical suggestions (e.g. in case of low blood pressure the patient is recommended to lie down on the back and to raise the legs) or warning about the enabling of at need therapy (e.g. an increased dose of diuretic).

The interactions with the user, i.e. questionnaire filling and displaying messages, are delegated to two personalized agents, the questionnaire and the dialogue agent. These two agents keep track of the user interaction and are responsible for the actual natural language generation of the output shown to the user in the PIPS Portal. Figure 3 summarizes the interactions between the specialized agent and the other agents.

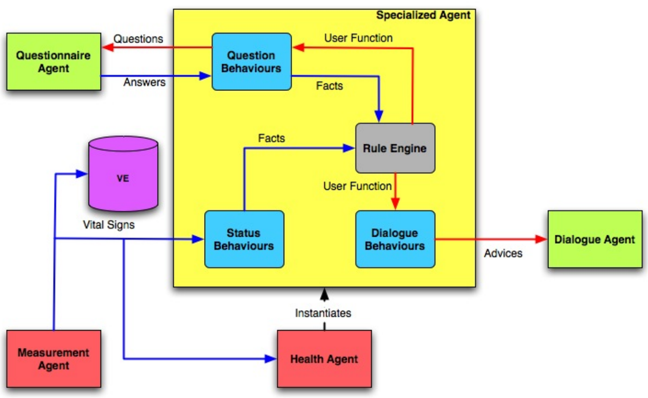


**Figure 3.** Agents interaction in clinical scenario.

In John's case, the analysis of the collected vital signs (increased weight, low blood pressure, high heart rate) indicates a body fluids accumulation, which is confirmed by the symptoms collected via the questionnaire (weakness, shortness of breath, reduction of diuresis, etc.) and additional vital signs (low oximetry). As a result, he is suggested to resume his diet (strictly adhering to his water intake regime) and a new therapy with an augmented dosage of diuretic is set by the system for him (updating his agenda). This situation is particularly complex because the diuretic has a long term effect, around 24 hours, and the abnormal condition must be monitored in the following days, alerting the doctor if the symptoms remain. The diuretic therapy change is prescribed beforehand by the doctor who, along with the normal dosage, will provide the augmented dosage to be taken in case of suspected fluid accumulation. This change of therapy is performed by another specialized agent, the prescription agent, who queries the PIPS knowledge base in order to discover which of the currently prescribed patient drugs have a diuretic effect. For all those drugs at need repetitions are activated if present.

John's doctor is also warned of the situation. On her PIPS Portal home page, or cellphone if so configured, she will receive a message that John's therapy has been changed according to her indication and she will be able to check the collected data (both vital signs and questionnaire answers). At that point she can take an informed decision and react appropriately (for example, fixing John's therapy, contacting and reassuring him or inviting him for a checkup).

In the scenario presented above the health assessment has been triggered by the identification of out of range vital signs. Notice, however, that symptomatic conditions may arise even if all relevant vital signs are inside their respective reference values. For this reason, the patient is given the ability to assess his health status at will starting autonomously a new questionnaire.

In the following days the system will react differently accordingly to the new status of the patient. For instance, if the body fluid accumulation detected previously worsen or anyway doesn't improve, the modification to patient therapy is immediately suspended and his doctor timely alerted. The whole rules base spans several possible patient health states (green or default, yellow, orange and red in case of hypertension) and has been developed in collaboration with San Raffaele Hospital coronary care unit doctors.

Finally, John can access his updated prescription from other PIPS enabled devices present in his home. For instance, we have realized a smart drug cabinet equipped with radio frequency identification technology[6], able to recognize the user that is accessing it and the items that he is taking out. Triggered by such an action, the PIPS System is able to check if the selected item presents any health risk for the user and warns him. In the described scenario, for example, PIPS can recognize that John is picking up a box of Polase[7], maybe because a friend suggested him that such drug may help when he's feeling weak, and alerts him that the selected item interacts with his current prescription, causing an accumulation of potassium in the blood. Of course, even in this case the component that is taking care of the advice generation is the DSS: the drug interaction agent, a knowledge discovery agent that closely collaborate with the prescription agent, receives the identification code of the selected drug and the current user, queries the PIPS knowledge base and identifies all possible interactions with the patient prescription (Figure 4).

Both the information on drug interactions and on drug effects (which enables, for instance, to select those with diuretic effects out of the user prescription the drugs) are stored in the PIPS Knowledge Management layer. For this purpose a domain specific ontology, the PIPS Drug Ontology, has been developed by the University of Liverpool. This ontology defines concepts like drug, active ingredient, interaction, ATC classification[8], etc. Moreover, national drug databases

[5] At each elaboration step more than one question may be planned, in which case they are all presented to the user. In a first version we presented the user only one question at time, but the questionnaire resulted too long and the doctors required to modify it.

[6] Similar in the approach to [18] and [15].
[7] A sodium and potassium integrator.
[8] Anatomical Therapeutic Chemical (ATC) Classification System, divides drugs into different groups according to the organ or system on which they act and their chemical, pharmacological and therapeutic properties [12].

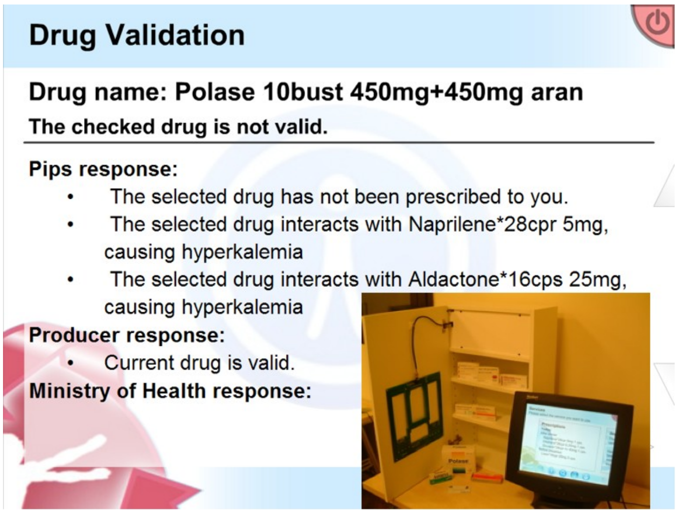


**Figure 4.** PIPS Smart Cabinet and drug interaction alert.

have been connected to the PIPS KM layer by mapping their structure on the Drug Ontology. Exploiting both the ontology definition and the information contained in those databases, the PIPS semantic engine is then able to satisfy the drug interaction agents requests.

This scenario demonstrates some of the key benefits that a system like PIPS can provide: constant monitoring of patient health status enabled by the integration of self-care networked measuring devices, complex decision support system and new communication technologies, just in time abnormal health condition detection for chronic patients, integrated access to patients continuity of care records, personalized advices to improve health status.

## 4.2 Nutritional Scenario

One of the pillars upon which PIPS stands is nutrition. It provides a range of services integrated in the life of the person, with the main objectives of, on the one hand, providing information related to the person's daily nutritional needs, taking into account the personal information and on the other hand, giving support to the nutritional specialists, in order to allow a follow up of the way the person is responding to their recommendations or prescriptions. This section describes a scenario in which some of these services are highlighted.

The scenario introduces Jose Alvarez, a 45 years old person, who is overweight and intolerant to lactose. Jose presents a sedentary profile and his nutritional habits are poor. He is under the supervision of a nutritionist, trying to lose weight by following a diet, which is personalised to his food likes, and having to do some physical exercise. Jose is also concerned about buying, eating and cooking the right food, always taking healthy products and avoiding risky ones.

The scenario starts one Monday when Jose goes out from his office and decides to do the shopping in the supermarket. When he arrives he decides to check his diet on his mobile phone. As Figure 5 shows, PIPS then sends him his diet for that night, so he starts buying the products he is able to identify in the diet, trying to remember the ones he lacks at home.

One of them is extra virgin olive oil. He takes a bottle from the shelf and tries to identify the nutritional properties of that specific oil. That product does not have a label where these data are presented, so he asks PIPS for them. Through his mobile phone, he takes a picture

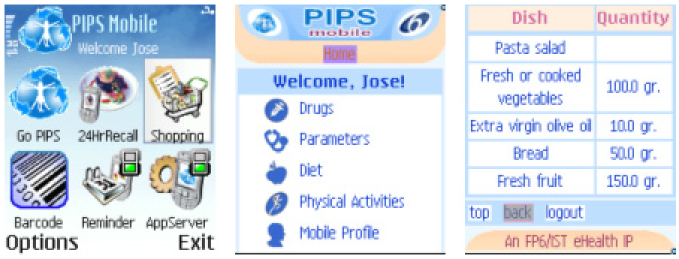


**Figure 5.** The patient can check his diet

of the bar code of the oil bottle[9]. PIPS system reads it and sends it to the DSS, where an agent takes it and checks the product nutritional properties, identifying possible threats for the user. In this case, the olive oil is fine for him, so he decides to buy the bottle of half a litre and annotate it in the system. Figure 6 presents the three screens the user can see on his mobile.


**Figure 6.** Product information without alerts

Once at home, he decides to cook the dish prescribed in his diet, and PIPS provides tools for helping him to do so. He decides to create a shopping list for the rest of the week, so he can receive support from PIPS at the supermarket. An agent retrieves the diet of the person for the specified period of time, and calculates the needs of the person in order to be able to cook the dishes specified. The recipes dishes contain the quantity of each ingredient needed, although these quantities are represented in different measurement units, such as international system units, or household units (cups, teaspoons, handfuls, etc.). These units can be representative when the person is trying to cook the recipe, but they are meaningless when he is at the supermarket. The shopping list agent sends these quantities and units to a knowledge discovery agent responsible for converting from one measure to another. An example of how this agent works could be the following one: imagine the shopping list agent wants to know how many grams is a tablespoon of olive oil. It calls the agent asking it to perform the MEASUNITS_ACTION_GET_UNITS_2_IS action, passing olive oil, tablespoon and grams as parameters. From this point the agent detects that the first unit (tbs.) is a household unit, and olive oil belongs to the liquids group, so it looks in its knowledge base to find how many ml are in one tablespoon of liquid. Its knowledge base indicates that one tablespoon of liquid is 25 millilitres. The agent then converts the millilitres into grams, which was the original requested unit. Now, it is able to retrieve the density of olive oil, 820 Kg/cm$^3$, so it multiplies this number by 25ml and divides it by 1000, getting

[9] A barcode reading application for mobile phones has been developed by the project, working with almost all Nokia series 60 phones and field tested on different lighting conditions.

20.5 grams as final result.

After this process of unit conversion, the shopping list agent, knowing the current quantity of each food that the person has at home (for instance, in this case, he bought half a litre of olive oil the day before), is able to calculate the quantity needed of each ingredient, for cooking the dishes in the diet for the rest of the week. From this point, the agent creates the shopping list, including all these foods, and representing the quantity of each of them in standard commercial sizes. Therefore, once the person requires the shopping list information, it will be presented in a way in which the user will be able to easily identify the products in the supermarket. It is important to stress the fact that the agent only includes foods in the shopping list, without any brand or commercial name, so the list includes things like oil, rice or tomatoes.

Going back to the scenario, it's already Tuesday, and Jose goes out from his office and he decides to go to the supermarket to do the shopping for the rest of the week. In this case, once he is at the supermarket, through his mobile phone, he is able to retrieve the shopping list that he generated the night before. In the list he finds ”pasta”, so he takes a pack of fresh tortellini filled with meat. There are no indications on the product about its real content, and he is not confident that the product is lactose-free, so he decides to check the product. This time, he does this action through the shopping list service in the mobile phone. He takes a picture of the bar code of the tortellini and it is sent to the PIPS via a web service. There, the shopping list agent identifies the product, and contacts the user characterization agent in order to retrieve the list of food to which Jose is intolerant, it also retrieves the nutritional info of that specific product. It detects that the product contains lactose, and at that point, the agent creates a list of alternative products, products that are lactose free, and belong to the same food category as the tortellini. Jose, now, is able to take one of the alternative products, being sure that it will not be pernicious to his health. If the user decides to buy more food on the list, the shopping list agent is again able to identify to which item in the list the product being bought is linked. For instance, in our case, the list contained ”pasta”, when the user takes a concrete box of spaghetti of one commercial brand, the agent is able to identify that this product corresponds to the item pasta in the list, so when the user buys it, the system can check it out from the list. Figure 7 and Figure 8 represent the screens the user interacts with on his mobile during this scene.

In order to make inferences like that “spaghetti” is a kind of “pasta” or that “olive oil” is a “fluid”, the agent accesses via the KM layer the PIPS nutritional ontology [9], where all these concepts (i.e. products, intolerances, food hierarchy, etc.) are represented and related.

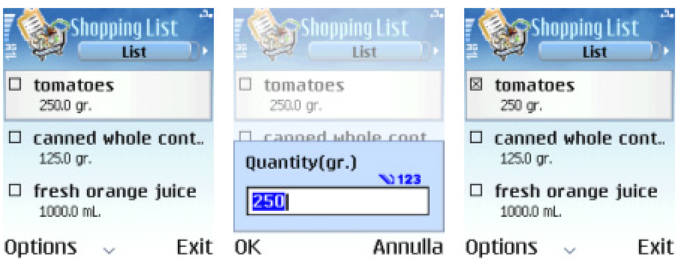


**Figure 7.** The user is able to check his shopping list and add products

PIPS is not the first project that is exploiting barcodes of grocery items to provide mobile services to the user. For instance, the Finald based TIVIK project [17] has realized a similar solution and field tested it with 100 users. In the United States it is possible to buy a portable barcode reader wirelessly coupled with a mobile device able to recognize 300.000 grocery items and to manage a shopping list while at the supermarket [1]. However, PIPS represents the first attempt to consistently link food product nutritional information with user profile to provide personalized decision support.

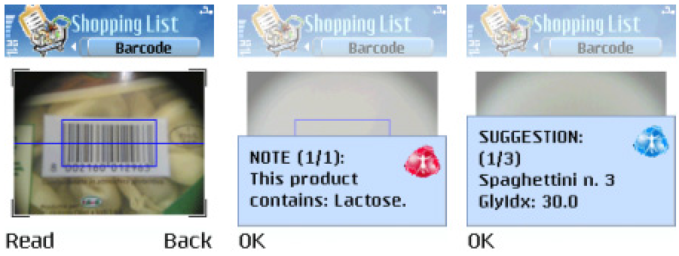


**Figure 8.** The product contains lactose, he receives alternative products

Apart from these tools, PIPS includes a set of nutritional profiling and monitoring tools, such as food frequency questionnaires, 24 hour recalls or physical activity questionnaires. All them together allow the nutritionists to evaluate and validate the progress of the patient during the of the prescriptions, and react to correct possible deviations caused by the no-adherence to the treatment.

This scenario is an example of how this type of system, combining different technologies, such as the described multi-agent architecture, or domain ontologies, can help the person to adhere to a treatment, such as a diet, by providing information that can be vital when the person has to make a decision that could affect his health, helping achieve the prescription goal and finally, providing it at the place and time when it is needed.

## 5 Conclusion

In this paper we introduced the PIPS system, an integrated environment for the delivery of health care, and support for a healthy lifestyle. The need to accommodate in the system many types of users, with different roles and needs, and many devices lead to the natural choice of using a multi-agent system approach to the analysis and design. While many parts of the PIPS system are implemented using more traditional software engineering approaches, the dynamic aspects of the PIPS decision support layer make such approaches unsuitable.

In this paper we presented the PIPS decision-support processes by describing the resulting architecture of the system, and two application scenarios that demonstrate the usefulness of the multi-agent approach. A first version of the system has been realized and it is currently stress tested in order to evaluate the performances and response times under different load conditions. In the next months the PIPS system will be deployed in San Raffaele Hospital (Milan, Italy) and in La Fe Hospital (Valencia, Spain) at the end of the project. A substantial evaluation phase will then follow which will assess the effectiveness of the system in addressing health-care objectives like adherence to a therapy or health behavioural changes, which should produce a positive impact in the improvement of the healthcare provision processes.

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