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Social Cloud-based Cognitive Reasoning for Task-oriented Recommendation

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Abstract

The Social Internet of Things (SIoT) is recently being promoted in literature for enabling the integration of devices into users' daily life. This integration can be achieved by taking advantage of the inter-connectivity and the user-friendliness offered by Social Network Services (SNS). The novel SIoT paradigm opens the door for studying the intelligence mechanisms required to enhance services adaptability. We study the integration of cognitive reasoning into SIoT for providing recommendation of quotidian tasks in smart homes. In order to achieve situation characterization, reasoning about physical as well as social aspects of context is required. Thus, as a service built on top of Social Cloud (SoC), we propose an intelligent recommendation (InRe) framework. This framework applies the reasoning mechanism on context elements which are represented using ontologies. ThigsChat is provided as a proof-of-concept prototype. Initial experiments indicate a considerable improvement in adaptability of recommendation results to users' situations.

Keywords: Social Internet of Things (SIoT); Social Network Services (SNS); Context-awareness; Social Cloud (SoC)

1. Introduction

The Internet of Things (IoT) paradigm covers a diverse range of technologies including sensing, networking, computing, information processing, and intelligent control technologies [1]. In practice, the large scale, complexity and the highly heterogeneous nature of IoT act as the main challenges facing IoT technologies. Recently, a new research stream has emerged to tackle some of IoT challenges, which is referred to as Social Internet of Things (SIoT) [2]. The SIoT paradigm represents an ecosystem that allows people and smart devices to interact within a social framework resembling traditional Social Network Services (SNS). On top of this framework, applications and services can be provided in a user-friendly manner relying on Web technologies. SIoT builds on the emerging concept of social objects [3] in which smart objects become exposed to the Web, allowing the autonomous and proactive interactions with other people and objects.

Handling the variety of contextual data, which exists in SIoT for intelligent decision-making is a major challenge for providing adaptive services that match users' needs. It is also the major contribution of this article. Typically, context within IoT is being dealt with in a reactive way. That is, the objective aspects of context, which describes existing states of entities, for example, certain location, states of a device, user identification, etc., are considered widely for context-aware decision-making [5]. However, in order to provide adaptive services to meet users' specific situational needs, the subjective aspects of context are required [6]. These subjective aspects describe the cognitive states such as user's goal, preferences, mood, etc. Considering both objective and subjective aspects of context is proposed in this article as an approach for characterizing users' situation for intelligent recommendation in the SIoT.

Nowadays an increasingly growing number of smart objects and devices are being connected to the Internet. To benefit from the connectivity and the precious data generated by these objects smart spaces and building automation solutions and services are increasingly proliferating. However, there's still a huge need in improving the intelligence mechanisms which are required to make such solutions and smart services more adaptive to users' needs and conditions specially to aid senior people and those who need a specific medical care like people dealing with dementia.

Thus, in this article, we propose a novel reasoning mechanism - namely, cognitive reasoning which focuses on combining objective as well as subjective aspects of context for characterizing users' situations. This reasoning mechanism is applied within a task-oriented intelligent recommendation system, namely InRe, which recommends quotidian tasks based on users' situation in a smart home. InRe is fitted to users' situational goals, which we detect by means of schedules, preferences, daily habits as well as the devices and smart home conditions. From an architectural viewpoint, InRe is proposed as a service built on top of Social Cloud (SoC) to benefit from the contextual data extraction, reasoning and storage capabilities which is provided by SoC. From a technological viewpoint, we adopt Web Services at the device level to ensure network navigability and direct human-to-object interactions. Thus, an application named ThingsChat is provided to illustrate the operation of InRe in a smart home. We consider the light-weight version of W3C Web Service, Device Profile for Web Service (DPWS) [7] which does not require devices with powerful capabilities to fit into the system. Our initial experiments show in adaptability of recommendation results to users' situations.

The rest of the paper goes as follows; the article related work is discussed in the following section. An overview of our proposed cognitive reasoning mechanism is shown in section 3. Then in section 4 our proposed InRe recommendation framework is presented. ThingsChat implementation as well as the empirical evaluation is shown in section 5. Finally, the article is concluded in section 6.

2. Related Work

Cloud computing offers a great chance for allowing access to shared computer utilities. These utilities are capable of accommodating large-scale and heterogeneous application requirements. It then enables the composition of appropriate cloud utilities which can best fit the need of given applications [8]. Chard et al. [13] provides an explicit definition for SoC "A Social Cloud is a resource and service sharing framework utilizing relationships established between members of a social network". Hence, the SoC emerged in literature with a potential to realize the vision of SIoT. That is, SoC allows platform-independent sharing of physical resources and services based on the trust existing between nodes on the social network of everything. On the other hand, Atzori et al. [9] is among the few who first introduced the concept of the SIoT as an evolutionary step following IoT. In which, social relationship among objects and people can be established in a similar way to human relationships. This suggested social structure of people and object can improve network objects navigability and discovery in a manner similar to traditional SNS.

Achieving intelligent decision making in SIoT environments is a challenging issue. That is, intelligent systems should act beyond filtering from a list of pre-stored services. It rather should be equipped with reasoning methods to monitor and model situations in order gather appropriate knowledge necessary for situational decision making [5]. In the PhD dissertation presented by Rasch [10] a thorough study for realizing smart assistant in smart homes is provided. In which, a collaborative filtering-based recommendation system is proposed to filter users' preferences for suggesting a list of actions to be performed at home. One issue is provided in this study as an interesting topic for future investigation is context-awareness. Where users' short term goals preferences, geographical information, calendar events extracted from social networks, etc. can be exploited for the purpose of detecting current context of users and thus provide relevant intelligent recommendation [10].

The work presented by Muñoz-Organero et al. [11] provides a collaborative filtering-based recommendation system for IoT smart services. It takes into account user location and interaction time to recommend scattered, pervasive context-embedded networked objects. However, collaborative filtering-based recommendation systems rely on a straightforward user model. These user models consider a user as a vector of item ratings where additional profile information including preferences, location, status, etc. is considered as extensions for the basic user model [12]. This kind of recommendation however ignores users' situational needs. In which, users' preferences, status and other profile-based information may vary from one context to another. In this sense context-aware recommendation systems are more relevant to meet users' situational short term goals.

3. Cognitive Reasoning Mechanism in SIoT

This article proposes a cognitive reasoning mechanism which combines objective as well as subjective contextual elements 1- for characterizing users' situations, 2- for inference about situational goals and thus tasks that would fit such goals. This reasoning approach is applied by a task-oriented intelligent recommendation system, namely InRe, which generates a list of quotidian tasks that are relevant to users' situations in smart homes. Thus, in order to achieve intelligence in SIoT, which entails situation characterization and proactive decision making, a detailed contextual model of users', social objects and their surroundings environment is needed. Utilizing Semantic Web Technologies would provide a scalable means for context-aware applications and services to access and reuse contextual data available in SIoT. While knowledge reuse is one important advantage of ontology, in this article we build on domain ontology such as friend-of-a-friend[1] and Semantic Sensor Network[2]. These domain ontology provide generic vocabularies that suit context modeling requirements. However, we extended these ontologies by adding new vocabularies aiming to utilize the context model for generating task-oriented recommendation of smart services in smart homes. In our SIoT context model we suggest two kinds of relationships between people and objects: Ownership, and authorization to use. Owners of devices or building managers can authorize users to establish social relationships with objects surrounding them (see Figure 1(a)).

3.1 SIoT Context Representations

The term ontology refers to the formal description of concepts which are often conceived as a set of entities, properties, instances, functions, and axioms. The Web ontology language (OWL) in this sense defines and instantiates ontologies in a manner that let Web agents interpret and exchange information based on a common sense vocabulary. Smart spaces typically cover a range of environment types like homes, offices, etc. Additionally, considering the resources limitation issue in most of smart spaces, including limited CPU speeds and processing capabilities, a two-layer hierarchical ontology model is adopted in this article: l- general upper ontology (see Figure 1(a)) representing general concepts and ontological classes in smart spaces and 2- domain-specific ontology (see Figure 1(b)) which represents details existing in smart homes.

The contextual model shown in Figure 1(a) - (b) represents context as ontology instances with their associated properties in which this combination is referred to as context markups. The upper ontology fragment shown in Figure 1(a) represents context markups with relatively low changing rates. For instance, user preferences, relationships with devices, and devices associated services which are a kind of data that does not change quite often. Whereas the lower ontology fragment shown on Figure 1(b) shows resources which provide dynamic contextual data like location, time, person status, etc. In this sense the automation of context markups is required by the applications running the ontology model. For instance, consider a mobile-device application which detects user location whenever the user presence at a certain spot exceeds 5 minutes. Thus, the mobile application composes the following OWL markup to announce user Nadia presence at the supermarket:

```
<Person rdf:about="#Nadia"> <hasLocation
rdf:about="#Supermarket01"/> </Person>
```

Each OWL instance, like the one shown above, has a unique URI. Thus context markups can link to other definitions using these URIs. For instance, the URI (http://www.telecom-sudparis.eu/SIoTData#Nadia) refers to a certain user and accordingly another URI refers to the supermarket which is defined somewhere else in our system.

[1] FOAF, http://xmlns.com/foaf/0.1

[2] SSN, http://www.w3.org/2005/Incubator/ssn/ssnx/ssn

3.2 Three phases Situational Reasoning in SIoT

The SIoT context infrastructure, described above, lets applications running on top of it retrieve context using queries and it supports the inference of higher-level contexts from basic contexts. The notion of cognitive reasoning is proposed in this article to refer to combining the objective and subjective aspects of context in order to produce situational fitted recommendation list. The three phase situation reasoning model represents facts along seven dimensions corresponding to the so-called Seven WH-questions - what, where, when, who, with what, how, and why [14] (see Figure 1(c)):

- **1st phase – Situation detection**: In this phase basic contextual data are exploited to identify the main entities involved in a certain situation. Thus, spatio-temporal data to detect where and when an event is taking place are fetched. Then the relevant event type is matched once based on the user location. For instance, if user Nadia's location is detected at a certain time in the supermarket, then the event is defined as "shopping". Similarly when a foreign member is detected at smart home the event is defined as "Guest at home". Finally, the whole combination of user, location, time, and event type context markups forms a situation.

- **2nd phase – Situational goal retrieval**: This phase takes into consideration inferring high-level context from the basic context data fetched in the previous step. It represents contextual markups about user habits and history in similar previous situations in addition to user preferences, schedules. For instance, if user Nadia's habits are to do shopping on a Saturday while her schedule says she will be on trip on Saturday, so when she's close to the supermarket a reminder for her to do shopping would be considered as a situational goal.

- **3rd phase – Situation-based Task Filtering**: In this phase and based on the situational goals retrieved in the previous phase, a list of relevant tasks is generated. These tasks are then matched with smart services available in smart home. That is, the contextual aspects including service rating, environmental conditions, etc. are exploited for the elimination of irrelevant services.

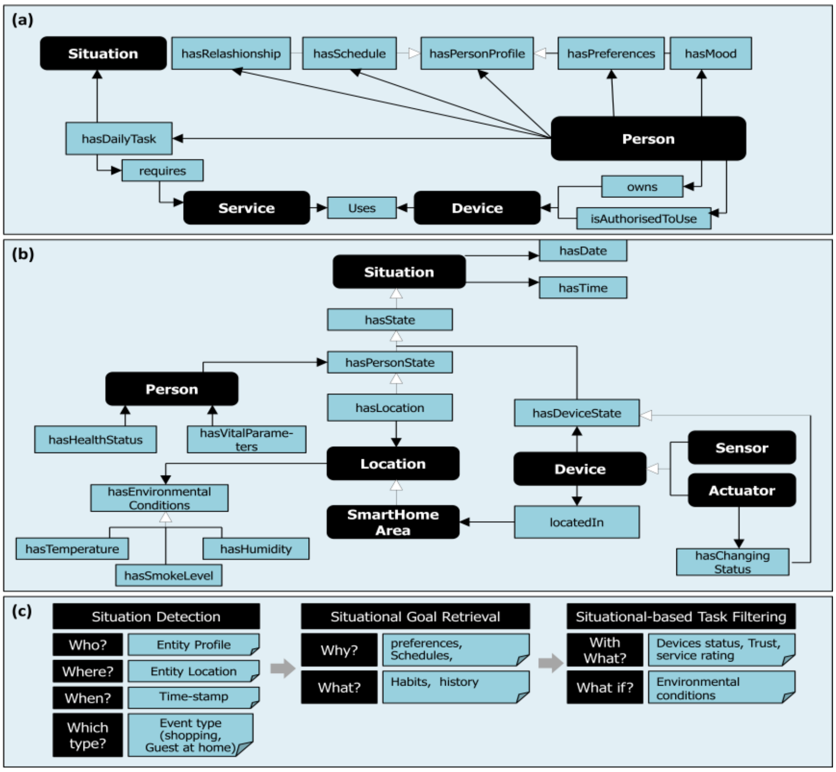


Figure 1. Context representation and use in SIoT. **(a)** SIoT upper-ontology fragment. **(b)** SIoT lower-ontology fragment. **(c)** Three phase situational reasoning in SIoT following the 7 WH basic reasoning questions.

4. InRe Framework: Towards Situation-aware Recommendation of Quotidian Tasks

Figure 2 depicts the overall recommendation system architecture which relies on the context infrastructure and the cognitive reasoning mechanism described before. The SoC is proposed from an architectural view point to store contextual data and all the reasoning and inference tasks. The framework consists of three main modules: the context management, the situation reasoning engine and the task navigator.

The user situation is first identified upon the triggering of system or user initiated events. In order to characterize users' situations and thus infer situational goals, additional contextual data are collected by the context enhancer component. Accordingly, the rule-based reasoning component sends queries to gather information about the situation relevant goals which comprise user preferences in relevant situations, schedules as well as devices status and environmental conditions. These contextual data are then semantically matched against SIoT situation Ontology. This ontology represents common sense knowledge about typical daily tasks which corresponds to situations, i.e., turning on the robot cleaner before having guests, preparing an up-to-date shopping list when user is shopping, doing laundry before a scheduled trip, etc. Thus, a list of tasks will be sent to the situation-based services filtering module. The services filtering module semantically matches tasks with corresponding smart services using SIoT quotidian-tasks ontology. Thus is generates a recommendation list containing smart services which corresponds the user situation. Actuation of the user selected services then takes place.

a. Context management

This module provides persistent context storage. It stores contextual markups which are gathered from context wrappers. The context wrappers are responsible for obtaining objective and subjective context from various sources such as physical objects, SNS profiles, etc. and transform them into context markups. These markups are described as OWL representations in order to make it accessed and reused by other components. This module also acts as an abstract interface for the situation reasoning engine module to extract desired context from the context enricher via queries. This lets the reasoning engine access context at the context management module.

b. Situation reasoning engine

This module is responsible for context processing and ontology parsing based on logic reasoning. In which, developers can create their own rules based on predefined format. Once pre-defined rules are triggered, facts about the situation can be extracted and thus certain related tasks can be recommended to the user. Table 1 shows an example of rule-based recommendation.

- When the user is shopping, the reasoning engine checks the status of appliances at home, it detects some devices which are low on supplements (e.g., coffee machine needs a new filter, printer needs ink, dishwashing machine needs salt). It sends a list of devices needing supplements.

```
type(?user, User),locatedIn(?user, ShoppingMall),
TimerHasValueGreaterThan(currentTime(), 07:00:00),
TimerHasValuelessThan(currentTime(), 08:30:00)
➔ situation(?user,AtShopping)
type(?event,AtShopping),type(?SmartHomeApplianceHasStatus,ApplianceStatus),
CoffeeMachineHasStatus (?ApplianceStatus,ChangeFilter),
WachingMachineHasStatus(?ApplianceStatus,Fine),
DishwashingMachineHasStatus(?ApplianceStatus,ChangeSalt),
PrinterHasStatus(?ApplianceStatus,ChangeInk),
TVHasStatus(?ApplianceStatus,Fine)
➔recommendation(?SmartHomeApplianceHasStatus,SupplimentsNeeded)
```

Table 1. Sample rules to infer users' situation based on context, location and the surrounding objects

c. Task navigator

This module acts as an interface for gathering basic context data, which can latter help infer more complex context, as well as display the situation relevant tasks. This module is also responsible for running situation based services filtering algorithm. In which this algorithm semantically matches situational goals against quotidian task ontology to determine which tasks the situation goals match to and which smart services can fulfill these tasks.

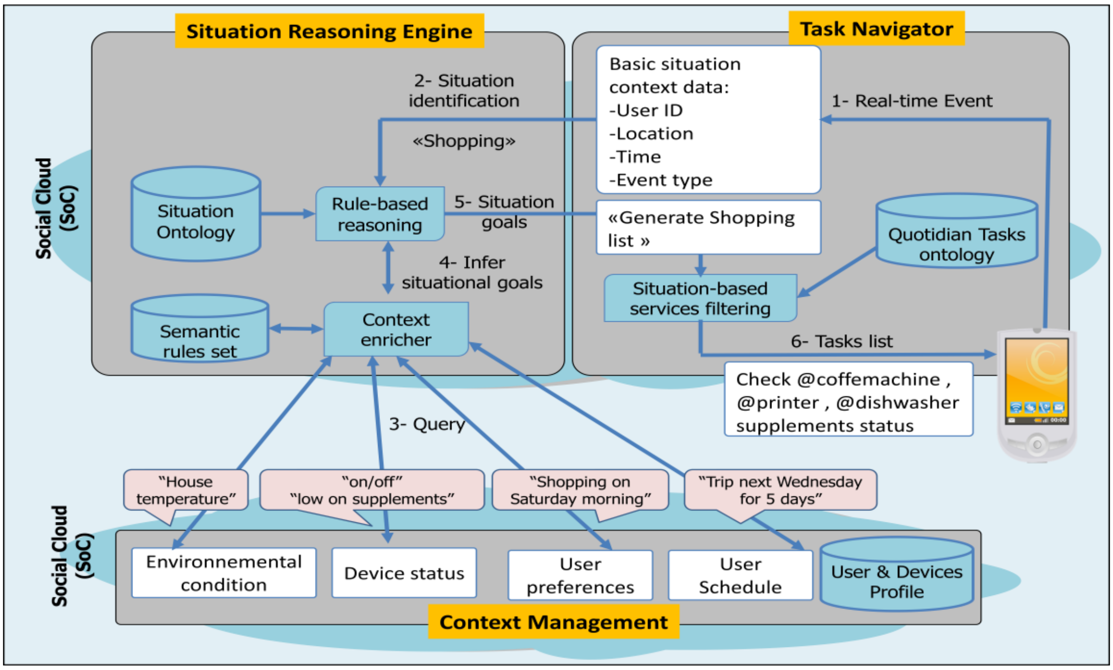


Figure 2. The InRe Framework

5. Application Prototype: ThingsChat

In this article we build on SNS to converge users' world, including social relationships, objects and standard Web services. In this sense, SNS provide an environment where peoples and objects profiles can be built and social relationships can be established. Thus, we build an SNS-based platform, ThingsChat, to enabling users to perform the following functions: create relationship with social objects (adding objects to the friends list), browse social objects, receive objects' status, and control objects and finally navigate through quotidian tasks recommendation. We adopt the following application scenario to highlight the main functions of ThingsChat (see Figure 3).

"Nadia is in her office and she received a text from her mother Leila who was near Nadia's house and asking if she can visit. Nadia sends a message to her smart home virtual group, in ThingsChat, informing about the visit and asking to recommend a list of tasks needed to make sure the house is ready to receive her mother. InRe, which is implemented as a module inside ThingsChat, checks first for Nadia's preferences and habits when receiving a guest at home, then the condition of the house and status of devices are checked before reasoning about a list of tasks required for intelligent recommendation. After Nadia approves the task list, device actions will be activated at home to prepare for the visit. While the services are running (i.e., house cleaning, dishes washing, putting the heater on, etc.), Nadia can directly interact with her coffee machine asking to prepare her mothers' favorite coffee when she arrives. The house is now ready to receive Leila."

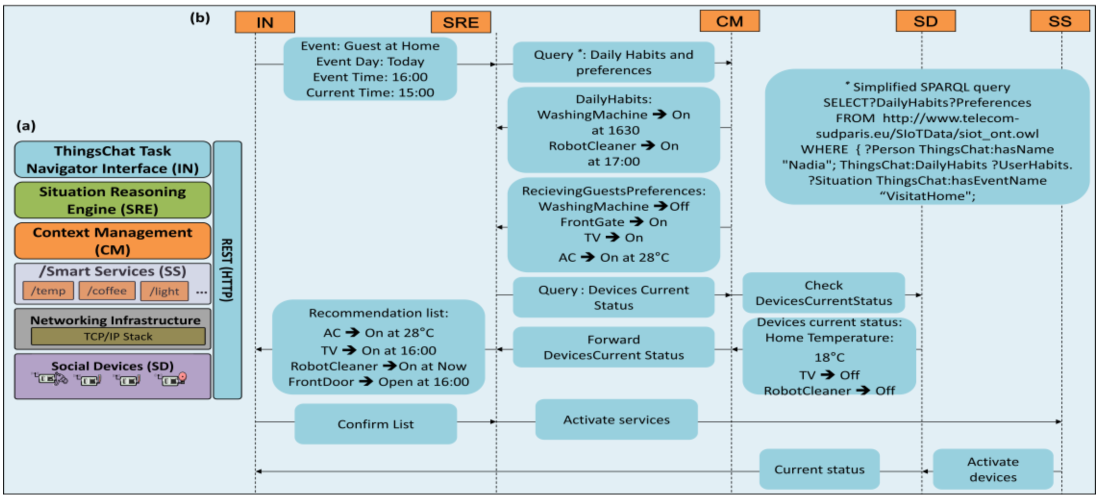


Figure 3. Application scenario. **(a)** Modules for actuating recommendation services. **(b)** InRe sequence diagram.

5.1.ThingsChat: Your Things are Chatting

As shown in Figure 4, ThingsChat includes two modules: DPWSim and ThingsGate, which perform the communication with the underlying DPWS standards. DPWSim, introduced in [15] is a Java-based simulation environment for DPWS devices with graphical interface to animate the operation of the devices. It uses WS4D JMEDS stack to handle DPWS protocols and is compatible with the DPWS Specification [15]. ThingsGate is a gateway which acts as a "wrapper" to present DPWS device functionalities in RESTful style, *i.e.*, in HTTP methods (GET, PUT, POST, and DELETE), to allow applications in the Web to seamlessly interact with DPWS devices, and also to perform social networking applications. ThingsGate also provides a Social Device API to meet the requirements of designing an SNS.

ThingsChat platform is based on the open source phpBB Social Network with Linux/Apache/MySQL/PHP stacks in the background. The original user profile in phpBB database is extended to store information about the gateway IP address. This information is unique for each device and used for the communication between ThingsChat and social objects (through Social Device API in ThingsGate). Additionally, level of authorization for each object, which enables it to be seen within a home or office network, can be set by object owner and stored in object profile. Thus, relationship can be established between users and objects by adding a certain object to my contact list as a "Friend". Figure 4 shows snapshots of ThingsChat. Listing 1 is an example of a user in ThingsChat asking her coffee maker to switch on by simply mentioning the device in her status update.

```
POST /mention.tsp HTTP/1.1
Host: http://157.159.103.10:8080
device_name=CoffeeMaker&post_id=135&text=switch%20on
```

Listing 1. POST message sent to device to switch it on when user mention the device on status share.

InRe is deployed in a separate server running Apache Tomcat, using Jena library for semantic data manipulation and the integrated reasoner for inference functionalities. The InRe collects information about Profile from the Jena reasoner and the inference engine and matches them with reasoning rules. This also provides RESTful API for the access from other ThingsChat.
We also develop a small module of NLP inside the InRe module, to detect and process conversation-based events i.e., chatting. This NLP is based on the profile of each device at the setting-up phase to get the keywords of the device's functions. It also includes a set of rules for obtaining the meaning in English context. Output from NLP is then converted into semantic format and processed by the InRe, to match with the list of events stored in the context knowledgebase and to generate a recommended list of tasks. Listing 2 delineates the event called Guest at Home.

```
@prefix : <http://www.telecom-sudparis.eu/siot_data#> .
@prefix siot: <http://www.telecom-sudparis.eu/siot_ont#> .
:Visiting
        a siot:ReceptionEvent ;
        siot:hasVisitor "Leila" ;
        siot:locatedAt :NadiaHome ;
        siot:time "15:30" .
```

Listing 2: Data of Leila's visit from NLP is stored in N3 format. They are processed by Inferred Profile to get a specific list of recommended tasks at Nadia's home to serve Leila based on the predefined Visiting event.

Figure 4. ThingsChat. ThingsGate is accessed by using smartphone via the mobile Web interface to discover and manage devices at virtual home of DPWS devices created in DPWSim. Below are different ways for the communication between people and devices. (i) There is a user Nadia sending Home Appliances group on ThingsChat to ask for receiving her mother Leila who is coming home while Nadia is still at the office. (ii) InRe accesses Nadia and Leila profile to recommend a list of services to be done at home, i.e., cleaning, opening the external gate, etc. (iii) Nadia accepts then most of the recommended tasks except the TV to be switched on. She also can directly chat with the coffee maker to prepare a coffee when her mother arrives.

5.2.InRe Performance Evaluation

Context can be incorporated in various stages of the recommendation process. In SIoT giving the richness of contextual data coming from cyber, physical and social worlds, scaling down the amount of contextual data which is needed prior to decision making is essential. Thus we developed InRe based on Pre-filtering context paradigm [12]. In which, based on a certain context, the semantic rules for recommendation generation are to be performed against only the services with matching properties, i.e., service input and output.

We evaluated InRe task filtering effectiveness, which indicates the quality of recommendation. For this we calculated Precision, Recall and F-measure values for some event-based recommendation scenarios. As shown in Equations (1) – (3), Precision (*p*) is the ratio of the number of relevant services to the total number of recommended services, whereas, Recall (*r*) is the ratio of the number of recommended relevant services to the total number of relevant services existed. The F-measure is the measure of the testing accuracy considering both *p* and *r*:

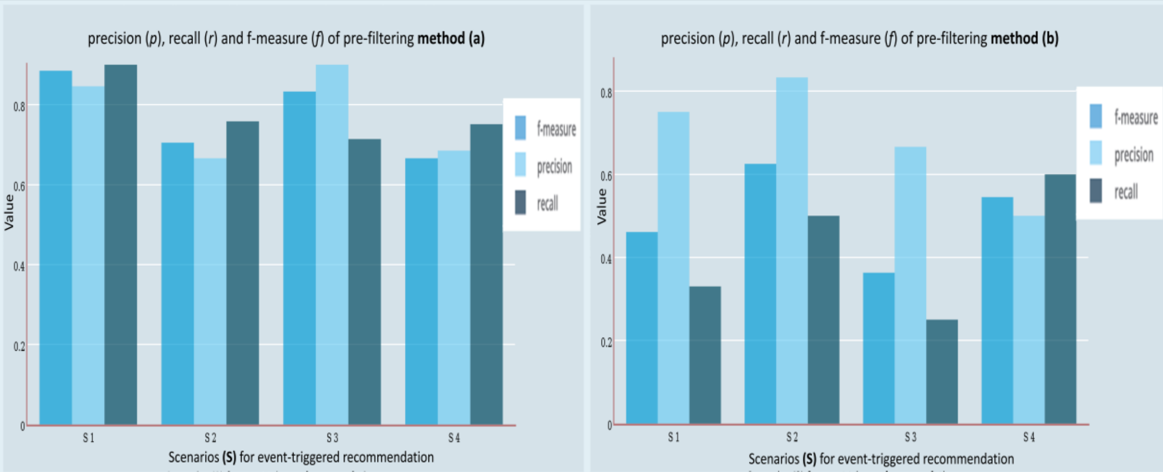
$$Precision = \frac{Recommended\ Services \cap Relevant\ Services}{Recommended\ Services} \quad (1)$$

$$Recall = \frac{Recommended\ Services \cap Relevant\ Services}{Relevant\ Services} \quad (2)$$

$$F - measure = 2.\frac{p.r}{p+r} \quad (3)$$

In order to highlight the significance of including subjective along with objective context in the process of recommendation pre-filtering, we calculated *p*, *r* and f values in 4 different scenarios for smart home events: 1- Having a guest at home, 2- Shopping, 3- High temperature in kitchen and 4- Having a conference call at home. We used a context synthetic dataset with 3,057 triples (or 600 OWL classes and instances). The matched recommendation result of each scenario is evaluated by comparing two context pre-filtering methods: (a) where user's daily habits, preferences, and environmental conditions are used for recommendation generation. (b) where time, location and environmental conditions are used. The results are illustrated in Figure 5 showing better performance of pre-filtering method (a) versus method (b).

Additionally, we tested the performance of ThingsChat platform to measure its responsiveness utilizing the following experiment setup: i) Virtual home simulated by DPWSim consisting of several DPWS devices including robot cleaners, TV, coffee maker, and floor lamps, ii) ThingsGate gateway, iii) the social network ThingsChat, and iv) The Intelligent Recommendation system (InRe). The ThingsChat and InRe are implemented on application servers on a computer with Intel(R) Core(TM) i5-2540M CPU @2.60GHz, 6GB RAM. DPWSim runs on a Windows 7 computer, and ThingsGate is implemented on a virtual machine on the same computer with one CPU, execution cap of 50%, and 512MB RAM. All servers are deployed in the same local network. We performed 25 tests focusing on the scenario of a user sending various messages to devices via ThingsChat and asking it to accomplish a task. For each message, sent users' text is analyzed, matched with semantic rules to convert it into a set of commands to be executed on the device. We achieved encouraging results with a response time stable at 2-3 second for each message sent.



S	f	p	r
S1	0.885	0.846	0.916
S2	0.705	0.666	0.7584
S3	0.833	1	0.714
S4	0.666	0.6851	0.7512

S	F	P	R
S1	0.461	0.75	0.33
S2	0.625	0.833	0.5
S3	0.363	0.666	0.25
S4	0.545	0.5	0.6

Figure 5. Results for applying pre-filtering methods (a) and (b) on event-based recommendation scenarios 1- 4

6. Conclusion

In this article we propose a cognitive reasoning mechanism for generating task-oriented recommendations for supporting users in finding appropriate smart services which correspond to quotidian tasks in smart homes. The recommendation results are fitted to users' situational goals. This reasoning approach aims at achieving intelligence in smart spaces, particularly smart homes, which would allow SIoT services to operate in an intelligent way to aid users in their daily lives. Our initial experiments which show stable results draw attention towards the great capabilities which could be achieved when incorporating SoC as an infrastructure for running the required reasoning processes as well as storing and managing the huge amount of contextual data. In the future, we plan to investigate and incorporate dynamic ranking of recommendation results in order to produce an adaptive ranked list of recommendation on-the-fly according to daily situations in various smart spaces. We also plan to investigate the utilization of trustworthiness in terms of security, privacy and usability as contextual aspects in the recommendation process with the integration between the SIoT and the SoC.

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