Hotel room personalization via ontology and rule-based reasoning

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Abstract

Purpose – The increasingly competitive hotel industry and emerging customer trends where guests are more discerning and want a personalized experience has led to the need of innovative applications. Personalization is much more important for hotels, especially now in the post-COVID lockdown era, as it challenges their business model. However, personalization is difficult to design and realize due to the variety of factors and requirements to be considered. Differences are both in the offer (hotels and their rooms) and demand (customers' profiles and needs) in the accommodation domain. As for the implementation, critical issues are in hardware-dependent and vendor-specific Internet of Things devices which are difficult to program. Additionally, there is complexity in realizing applications that consider varying customer needs and context via existing personalization options. This paper aims to propose an ontological framework to enhance the capabilities of hotels in offering their accommodation and personalization options based on a guest's characteristics, activities and needs.

Design/methodology/approach – A research approach combining both quantitative and qualitative methods was used to develop a hotel room personalization framework. The core of the framework is a hotel room ontology (HoROnt) that supports well-defined machine-readable descriptions of hotel rooms and guest profiles. Hotel guest profiles are modeled via logical rules into an inference engine exploiting reasoning functionalities used to recommend hotel room services and features.

Findings – Both the ontology and the inference engine module have been validated with promising results which demonstrate high accuracy. The framework leverages user characteristics, and dynamic contextual data to satisfy guests' needs for personalized service provision. The semantic rules provide recommendations to both new and returning guests, thereby also addressing the cold start issue.

Originality/value – This paper extends HoROnt in two ways, to be able to add: instances of the concepts (room characteristics and services; guest profiles), i.e. to create a knowledge base, and logical rules into an inference engine, to model guests' profiles and to be used to offer personalized hotel rooms. Thanks to the standards adopted to implement personalization, this framework can be integrated into existing reservation systems. It can also be adapted for any type of accommodation since it is broad-based and personalizes varying features and amenities in the rooms.

Keywords Personalization, Semantic rules, Ontology, Tourism, Guest, Sensors

Paper type Research paper

1. Introduction

The hotel industry is a critical part of the travel and tourism sectors. Its impact on the economic and social development of a nation can be quite huge, given that it presents

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opportunities such as creation of jobs, opening a nation to investments, protecting cultural values and promoting entrepreneurism (World Travel and Tourism Council [WTTC],2016). The hotel room is a fundamental product in the travel cycle, and it greatly impacts the experience of guests. Guests devote their time in the hotel rooms, also to relax and take time off after a day of business work or tourism. Most travelers today seek hotel accommodations with more independence, individualized attention in the services and experiences offered and a homely atmosphere. Personalization helps hotels provide better services to customers while improving efficiencies. The trend of guests seeking personalized hotel experiences based on their unique preferences requires hotels to innovate to meet this need (Amadeus IT Group, 2010). The demand for personalization of hotel rooms is also driven by the emerging nations' burgeoning middle-class, which is more diverse and has discretionary income, as well as the generation of millennials who crave instant gratification, exploration and smart spending (Richard, 2017). However, many hotels still provide the same lodging experience for all guests, a "one size-fits-all" approach, without taking into account the varying needs, preferences, demographics and backgrounds of the guests.

Hotel room personalization is challenging for many reasons. On one hand, new technologies can be used to this end; among them, Internet of Things (IoT) solutions. However, IoT devices are hardware dependent, vendor specific and not context aware (Du *et al.*,2016), implying difficulty in programming and limitation of their adoption. On the other hand, existing personalization systems do not always consider a user's context (Lian and Hui, 2014), which is key in providing effective personalization solutions. The situation is exacerbated with the many options available from various hotel service providers. A large number of information and communication technology (ICT) systems and applications are used in a hotel, supporting front-office, reservation, housekeeping, etc. (Quarshie and Amenumey,2016). Given the high number of ICT systems and the large amounts of heterogeneous data generated from various sources in hotels, there is a need for interconnection of these platforms, data integration and automated data processing.

The use of ontologies has emerged as an important component in offering personalized services in a range of systems including e-learning, library, image retrieval, route-planning, care for chronic patients, etc. However, in the hotel room domain, very few studies have been carried out to personalize services. Existing hotel and accommodation ontologies, such as Hontology (https://hdl.handle.net/21.11129/0000-000B-D314-0) and Acco (http://ontologies.sti-innsbruck.at/acco/ns.html), model the hotel in general, and lack important concepts and properties for the hotel room domain. This hampers the goal of ensuring that all involved in communication within the hotel room, such as computing systems and humans, speak a common language through shared and consistent meanings of terms. Furthermore, ontologies alone do not enable all the knowledge related to a given domain to be modeled (Boufrida and Boufaida, 2020).

This paper proposes a hotel room personalization framework based on the hotel room ontology (HoROnt), and an attached inference engine. To this end, the core ontology, modeling the hotel room domain (Ojino *et al.*, 2021), available at Github (https://github.com/ronojinx/ontology/blob/main/HotelroomOnt%20(2).owl), is: populated to create a knowledge base storing instances of the ontology concepts; used as input for a new module, a rule-based inference engine. The knowledge base allows to describe both room characteristics and services, and guest profiles. To support hotel room personalization, the framework considers individual guest characteristics, preferences and responds to changing contexts. Hotel guests are modeled via logical rules into the inference engine exploiting reasoning functionalities to be used to recommend hotel room services and features. Rules have been defined by analyzing textual documents and interviewing hotel domain experts.

Results confirmed that the proposed framework, based on HoROnt, enables the construction of interoperable innovative solutions, such as the personalized hotel room framework.

The rest of the paper is structured as follows. Section 2 introduces the problem of hotel room personalization. Section 3 illustrates the methodology used in the study. Section 4 describes the implementation of the knowledge base starting from the HoROnt core, and Section 5 is dedicated to the definition of the rules and their validation. Section 6 reviews related work. Section 7 concludes the paper and illustrates future work.

2. Hotel room personalization

Hospitality markets are shifting, and new customer trends are emerging where guests want a more connected, personal and informed experience (Talwar, 2012). Likewise, operators want to deliver on the promise, increase profits, optimize facility usage, decrease operation costs, increase customer loyalty, etc. For a hotel to compete effectively, it needs to establish a close relationship with its customers and meet their needs, which can be achieved through personalization. Personalization is the ability to provide content and services tailored to individuals based on knowledge about their needs, expectations, preferences, constraints and behaviors (Berkovsky and Freyne, 2015). It has become popular due to the numerous benefits it offers which include: enhancing loyalty, increasing user satisfaction, leads to revenue growth, increasing user motivation, decreasing expenses, improving learning gains and enhancing management efficiency. Normally, hotels have a range of visitors with varying backgrounds, interests and preferences that if treated in a similar manner will most likely opt for other providers. Unfortunately, most hotels do not know their customers well because they fail to offer personalized services (Răbonţ u and Niculescu, 2009).

Digitization has made it possible for personalization to be met using automated systems rather than through the attention of a trained staff member (Campione, 2021). In a smart hotel room, for instance, various services can be personalized including the devices, architectural elements, services such as entertainment, environmental variables like temperature, humidity, etc. The final goals of a hotel room personalization framework are exemplified in the following scenario, where ABC hotel provides personalized room services. When 25 year-old business executive Miss Lisa Parks from Paris, France, flies into Nairobi, Kenya and checks into ABC hotel on a Saturday at 2 p.m., during the cold July season, in her possession is a digital key that she downloaded upon payment when she booked the hotel room via the hotel's website. During the booking process, Miss Lisa filled up a reservation form in which she entered her personal details, some preferences and needs. The main attributes of the hotel room she booked was as follows: <*A premier room, with a balcony offering stunning views of the city. The room is 35 square meters in size and contains: a king size bed, individually controlled heating and AC system, 43 inch cable TV, chair oversized with ottoman, shower/tub combination, marble bathroom and high speed internet access among other attributes*>. Upon arrival, a bellhop carried her luggage from the reception and escorted her to the room. When she got into the room, Lisa found that the environmental variables had been set according to her needs and context. Additionally, there were room elements that had been provided as relates to her preferences. Based on Lisa's context such as the weather, time of the day, day of the week, the temperature of the room was set to range from 17°C to 21°C, humidity ranged between 30% and 40%, and the curtains were drawn to let in natural light. The room had a provision of type C plugs which are common in Europe, a docking station for the electronic devices she would be using for her business, a hair dryer, international French magazines and the TV channels had been set to French as the language of preference. Given that she is allergic to pollen, the bedding in the room was hypoallergenic. Furthermore, the room had a customized welcome note written in French. During the stay, the hotel noted and paid attention to all her needs including her special requests. At the end of her five-day stay, Lisa left the hotel as an ecstatic customer who vowed to make repeat visits and recommend it to most of her friends visiting Nairobi.

Ontologies can be used to support personalized services, providing a suitable knowledge base, whose content are used by an inference engine, according to the classical architecture of expert systems (Russell and Norvig, 2020). A basic unit of personalization is the user profile that summarizes user characteristics, preferences and behavior – which is then used to support provision of personalized services via ontology. Most personal profile ontologies model static information, thereby leaving out dynamic data on users' activities and behaviors. An ontology including static and dynamic properties of the personal profile is proposed in (Usip *et al.*, 2021). The authors present the enhanced personal profile ontology, which is designed to support software requirements engineering task allocation; a domain different from that of hospitality.

The framework proposed in this paper uses HoROnt for the knowledge base, which besides hotel room concepts, includes user profiles. Hotel guest profiles are modeled via logical rules into an inference engine. Rules have been defined by analyzing textual documents and interviewing hotel domain experts. Rules are expressed in the Semantic Web Rule Language (SWRL), which allows dealing with empirical knowledge, for example, "A guest who is a smoker should be allocated a smoking room which is away from the corridors." The framework can be integrated into a hotel information system and used: during the booking phase to capture guest's needs and prepare rooms according to their preferences; during a guest's stay in the hotel room to capture and satisfy his dynamic needs; and at the postbooking phase to analyze customer needs to serve them better.

3. Methodology

A range of data collection methods combining both quantitative and qualitative techniques were applied in the study. To design the framework and an experiment to test it, the main steps require: the creation of a knowledge base populating HoROnt with hotel room and guests' data and the definition of the rules for the inference engine.

As HoROnt already contains all relevant domain information to model hotel rooms, to create the knowledge base, we first populate it by adding sample data of 25 guests from Victoria Comfort hotel in Kisumu (Kenya). Guests' data were anonymized through the removal and recoding of personal identifiable information before being put into use. Data for guests' activities and the context were added using a public data set named ContextAct@A4H (https://amiqual4home.inria.fr/contextacta4h-dataset/) that was created by Lago *et al.* (2017) and is made up of data collected from a smart apartment Amiqual4Home, which is equipped with 219 sensors and actuators (a step in the direction toward achieving the goal of the Internet and Web of Things, which is to allow heterogeneous devices to communicate with each other). Thanks to the data gathered via these devices, the data set represents both actual activities and the context of standard daily living of a 28-year-old woman who lived in an apartment for one week in the summer of July 2016 and three weeks in the fall of November 2016. The data were annotated with high-level labels to reduce the number of different activities preserving the desired semantics while considering time and day as part of context.

The hotel room framework needs rules to represent expert domain knowledge to adapt services. Such rules have been collected by analyzing textual documents and from the results of structured interviews of hotel domain experts. As regard document analysis, anonymized user data were collected from a range of documents, including hotel reservation forms, satisfaction forms filled-in by guests upon departure and surveys about the preferences of guests. It is this data that were used in rules formulation. Structured interviews were used to gather knowledge directly in the form of rules from four hotel domain experts. The hotel domain experts included two hotel managers, a housekeeping supervisor and a front office reservation staff.

As regards the implementation of the framework, Cellfie plugin was used to bulk import classes, properties, instances and axioms from Excel spreadsheet into HoROnt, saving time and effort (https://github.com/protegeproject/cellfie-plugin). Semantic rules for the personalization framework are expressed in SWRL. To process SWRL rules and produce output to be used for personalization of the hotel room, the Drools Rule Engine in Protégé (www.drools.org/) was used. It was chosen due to its scalability, i.e. one can add new rules without having to modify the existing rules. The adopted inference engine was OWL Pellet (https://github.com/stardog-union/pellet), it was chosen as it is a complete open source web ontology language – description logic (OWL-DL) reasoner with good performance, extensive middleware and unique features such as support for reasoning with individuals and user-defined data types (Sirin and Parsia, 2007). Reasoning on knowledge represented using SWRL rules and OWL ontologies, OWL Pellet provides hotel staff with service personalization recommendations for individual guests.

4. The knowledge base: populating hotel room ontology

HoROnt can capture, represent and model hotel room domain knowledge in a way that can be understood and interpreted by both humans and machines. The core of HoROnt was developed via a range of steps using the NeOn methodology, which also suggests exploiting existing ontologies to deal with the complexity of building an ontology. The design and implementation of HoROnt is illustrated in detail in Ojino (2020) and Ojino *et al.* (2021). The explanation given in this section is abbreviated to that necessary to understand HoROnt's extension to create the knowledge base. As a first step toward this goal, HoROnt includes concepts defined in existing ontologies representing general and accommodation knowledge such as DogOnt, Hontology and SOSA/SSN. Then, new concepts were added to deal with room personalization. Core concepts, modeled as classes, are shown in Table 1.

After conceptualization, the ontology was implemented in the Protégé ontology development environment using a representational formal language, OWL-DL. The development process in organizing the classes within the hotel room domain started from the "Whole to Part." The core implemented classes are illustrated in Figure 1, while Figure 2 shows an extract of the class hierarchy.

The binary relations between individuals (class instances), such as the relationship between a room and a guest are represented as object properties. In HoROnt, a number of object properties were defined as illustrated in Figure 3.

Data properties are used to link individuals to data values. These properties can restrict individual members of a class to literals and schema data types. In HoROnt, 44 data properties were defined to attach rich information about the individuals as illustrated in Figure 4.

HoROnt is also enriched with over 33,000 sensor observation instances from the ContextAct dataset and 25 anonymized records of guests retrieved from Victoria Comfort Hotel. The data properties of instances of HoROnt are specified automatically using Protégé's Cellfie plugin according to values extracted from the data sets. Figure 5 shows sample instances added to the ontology via the Cellfie plugin.

As a result of the activities described in this section, a knowledge base is formed, representing the instance population, which is used for reasoning on the guest profiles.

Table 1.
Core concepts used in HoROnt

Class	Description
Activity	This is a user context concept that details the task that the guest is actively engaged in or is likely to be completed by the guest at a particular time in the hotel room
Booking	Is a reservation made for a hotel room
Guest	This concept represents the guest profile. It structures different characteristics of the guest while referring to their preferences for context and services to achieve personalization
Observable property	An observable quality (property, characteristic) of a Feature of Interest
Observation	An observation is the act of sensing to estimate or calculate a value of interest (Haller *et al.*, 2019). This concept is the *sosa:Observation* from the SOSA/SSN ontology that represents a complete observation event, which is finished when a result is availed. An observation is carried out by a sensor for the entire period that a guest stays within the hotel room
Preference	This concept refers to the guest's liking for specific services, environmental conditions or hotel room attributes
Property	The property concept holds information about different physical parameters that characterize a room space. For instance, light intensity in the working space may vary from the one in the sleeping area
Result	The result concept relates to a particular property of a feature of interest, such as an environmental condition. It is the *sosa:result* concept of the SOSA/SSN ontology, which is modeled as individuals and linked to the observation using the *sosa:hasResult* property
Room	The room concept is the main class in the ontology. It represents the limited dimensional region in which all-tangible or intangible particulars in a situation are located and where all interactions and events occur. It is the host platform upon which other entities are attached
Room element	Room elements are target entities offer a range of services to the guests
Sensor	Device or software (simulation) involved in implementing a procedure. Sensors respond to a stimulus, e.g. a change in the environment or input data from the results of prior observations, and generate a result
Service	Services provide specific functionality in hotel rooms based on the needs and preferences of guests. They are target entities that should adapt to the user. Some services are provided automatically, for example, lighting; or as part of the room offering by hotel staff, for instance, housekeeping
Space	This refers to an expanse in the hotel room meant for some activities. Spaces in a hotel room are defined for various purposes
Special need	Any difficulty that causes a guest to require additional or specialized services
View	The view concept refers to the aesthetic scenery provided from the hotel room. There are numerous types of views that can be offered in a hotel room and can result to extra charges for the room

5. The inference engine: rules definition and validation

To support hotel room personalization, the hotel room framework needs rules to represent domain expert knowledge; to this end, a number of rules have been defined and implemented in an inference engine for HoROnt. Rule-based reasoning is applied as it enables a more functional representation of guest profiles and allows the creation of highly expressive personalization components (Skillen *et al.*, 2013). The personalization of services via rule-based reasoning enables inference of additional services and tailoring of services to suit changing guest needs. Besides, rules are favored for use in the personalized hotel room framework due to their naturalness and ability to incorporate practical human knowledge in conditional if-then rules (Chowdhary, 2020).

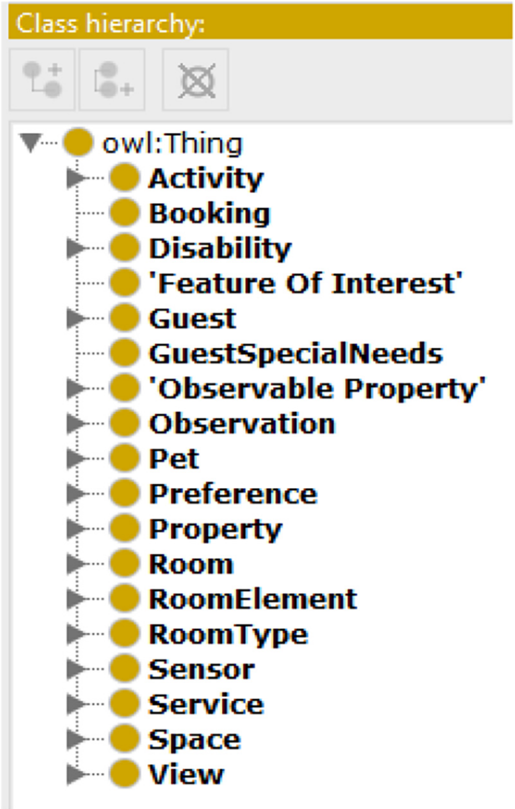

Figure 1.
Core HoROnt classes

Figure 2.
Extract of HoROnt class hierarchy

Figure 3.
Extract of object properties

5.1 Rule definition

HoROnt personalizes hotel room services by modeling the guest via a profile, which includes concepts such as the demographics, activities and preferences. The guest profile represents both implicitly and explicitly provided information about the guest. The latter may be gathered during the booking phase, when filling up hotel reservation forms or when rating the hotel service (in the course of stay), while implicitly provided information can be automatically retrieved by sensors (exploiting IoT) during the guest stay (e.g. to know the guest behavior pattern). The HoROnt guest profile contains both static and dynamic information in the hotel domain. In HoROnt, semantic guest profiles enable automatic classification of guests into specific categories depending on three dimensions, namely characteristics, preferences and context (Figure 6):

(1) *Characteristics*: This dimension includes the general demographics of the guest, such as name, gender, age, nationality, disability and contact information.

(2) *Preferences*: This dimension includes a guest's favorite items and likes, such as the favorite type of view and preferred lighting.

(3) *Context*: This dimension groups characteristics of the guest's situation including the activity that he or she is carrying out. The context consists of a lot of dynamic information, such as sensor data that captures a guest's activities and frequently changing preferences.

Figure 4.
Extract of HoROnt data properties

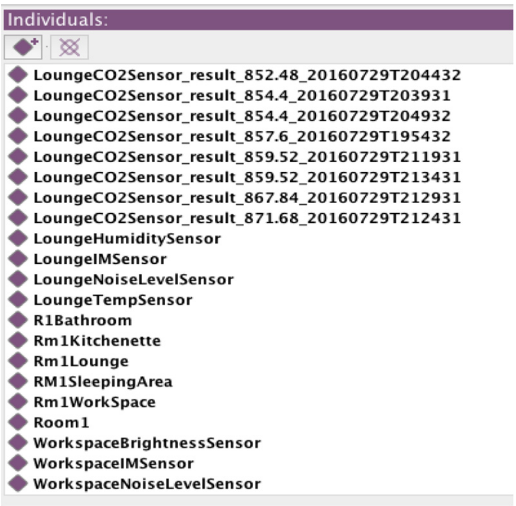

Figure 5.
Some instances in HoROnt

The semantic rules were obtained from documents analysis (hotel documents, hospitality articles, etc.) and from hotel domain experts' interviews. A total of 68 rules were gathered and coded using SWRL, a horn-like rule language that extends the expressivity of OWL2 language. SWRL was used in encoding the inference rules as it can express additional relations, thereby leading to more inferences being made from an ontology. Rules were then entered into a rule base to be used to infer the required personalization recommendations based on the guest profile. The SWRL Tab is used to implement the rule-based reasoning system in Protégé with the help of the Drools inference engine. Rule-based reasoning is used to map hotel guests to suitable services and amenities according to their characteristics, needs, preferences and context stored in the guest profile. The personalization rules were categorized based on the three dimensions in Figure 6. Examples of rules for each dimension are given in what follows.

5.1.1 Guest characteristics. Examples of the personalization rules used to recommend suitable hotel room services and amenities according to the guest characteristics and in SWLR are as follows:

- A Muslim guest who is a smoker is assigned a smoking permitted room that has a toilet which contains a toilet jet spray:

```
Guest(?g) ^ isSmoker(?g, true) ^ religion(?g,? p) ^swrlb:equal(?p, "Christian") ^isAllocated(?g,? r) ^SmokingPermitted(?r) ^hasSpace (?r,? b) ^ Bathroom(?b) ^ contains(?b,? c) ^ ToiletJetSpray(?c) -> isAllocated(?g,? r)
```

- A disabled guest is assigned an Accessible Room:

```
Guest(?g) ^isDisabled(?g, true) -> isAllocated(?g, AccessibleRoom)
```

- An elderly guest aged above 60 is assigned a room on the ground floor that is away from the lift:

```
Guest(?g) ^ hasAge(?g,?age) ^ swrlb:greaterThan(?age,60) ^ isAllocated(?g,? r) ^ Room(?r) ^ isGroundFooor(?r, true) ^ isCorner(?r, true)-> isAllocated(?g,? r)
```

It is worth noting that the element of serendipity is introduced the framework through some of the rules in this category. For instance:

- A couple of lodging for anniversary purposes is presented with an anniversary gift such as a cake in the room:

```
Guest(?g) ^ purposeOfStay(?g,? p) ^ swrlb:equal(?p, "Anniversary") ^isAllocated(?g,? r) ^ Room (?r) -> contains (?r, Anniversary_Gift)
```

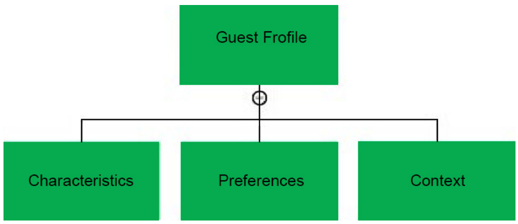

Figure 6. Dimensions of HoROnt's guest profile

- A just wedded couple that has booked a hotel room is presented with a wedding gift such as wine in the room upon arrival:

```
Guest(?g) ^ purposeOfStay(?g,? p) ^ swrlb:equal(?p, "Wedding")
^isAllocated(?g,? r) ^ Room (?r) -> contains (?r, Wedding_Gift)
```

5.1.2 Guest preferences. Example SWRL rules used to recommend suitable hotel room services and amenities according to the guest preferences are as follows:

- A guest who prefers video gaming is provided with a large screen TV in his room:

```
Guest(?g) ^ hasPreference(?g,? p) ^ swrlb:equal(?p, "Playing video
games") isAllocated(?g,? r) ^ Room(?r) ^ contains (?r, "Large screen
TV") -> isAllocated(?g,? r)
```

- A guest who has a preference for a room that has a view is allocated a room that has a View:

```
Guest(?g) ^ hasPreference(?g,? r) ^ hasView(? r,? v) ^ Room(?r) ->
isAllocated(?g,? r)
```

- A guest who prefers reading novels will have a bedside lamp in his room:

```
Guest(?g) ^ hasPreference(?g,? p) ^ swrlb:equal(?p, "Reading nov-
els") isAllocated(?g,? r) ^ Room(?r) ^ contains (?r, "BedSideLamp")-
> isAllocated(?g,? r)
```

5.1.3 Context. Sample personalization rules used to recommend suitable hotel room services according to the guest's situation (context) include:

- Preferred carbon dioxide levels while studying in the room.

If the guest is studying and the carbon dioxide levels are between 400 and 1,000 parts-per-million, then the guest is working using healthy carbon dioxide levels:

```
Guest(?g) ^ participatesIn(?g,? a) ^ Studying(?a) ^ sosa:Sensor(?s)
^ sosa:observes(?s,? o) ^ CarbonDioxide(?o) ^ sosa:hasSimpleResult
(?o,? t) ^ swrlb:greaterThan(?t, 400.0) ^ swrlb:lessThan(?t, 1000.0)
-> hotelroomontology:StudyingCO2Preference(?o)
```

- Preferred light intensity levels while studying.

If the guest is studying in the hotel room's workspace and the light intensity sensor has readings of values between 300 and 500 lux, then he is working using recommended healthy lighting conditions:

```
Guest(?g) ^ participatesIn(?g,? a) ^ Studying(?a) ^ Workspace(?w) ^
sosa:Sensor(?s) ^ sosa:observes(?s,? o) ^ LightIntensity(?o) ^ sosa:
hasSimpleResult(?o,? t) ^ swrlb:greaterThan(?t, 300.0) ^ swrlb:
lessThan(?t, 500.0) -> StudyingLightPreference(?o)
```

- Preferred light intensity while guest is in the toilet.

If the guest is in the toilet and the light intensity sensor therein observes readings of between 100 and 300 lux, then the guest is using recommended lighting conditions in the loo:

```
Guest(?g) ^ participatesIn(?g,? a) ^ GoingToTheToilet(?a) ^ Bathroom
(?b) ^ sosa:Sensor(?s) ^ sosa:observes(?s,? o) ^ LightIntensity(?o)
^ sosa:hasSimpleResult(?o,? t) ^ swrlb:greaterThan(?t, 100.0) ^
swrlb:lessThan(?t, 300.0) -> GoingToTheToiletLightPreference(?o)
```

5.2 Rules validation and results

The SWRL rules defined for HoROnt were loaded into Protégé's Pellet inference engine to be used by the forward chaining mechanism for their validation. The goal was to check whether on entering guest instances into the ontology (questions), the SWRL rules generated expected answers. In other words, when a guest precondition or a rule is satisfied by the data loaded into the HoROnt knowledge base, the inference engine must trigger the execution of a service or the setting of certain variables within the hotel room. To validate the framework, an evaluation of SWRL rules was performed based on sample questions. The sample questions were simulating real information from the experts and domain analysis. Forty questions were obtained, covering necessary concepts related to the personalization of hotel rooms. For instance, on entry of a guest who is a Christian, in his allocated room, a bible was placed. Two hotel domain experts checked whether the framework was able to generate appropriate answers.

The effectiveness of the inference algorithm in instance matching was compared against the ground truth, which was collected from hotel standards documents and experts' knowledge. Precision, recall and F-measures compare an expected result and the actual result. Precision of the hotel room personalization framework is calculated using equation (1):

$$Precision = \frac{No\ of\ correct\ recommended\ items}{Total\ No\ of\ recommended\ items} \tag{1}$$

Given that the hotel domain experts approved 36 of the 40 rules classification as accurate, precision was calculated at a high level of 90%. This indicates that most of the information in the ontology is useful for offering personalized services to guests.

Recall shows the number of recommended items that are correctly detected in contrast to all the knowledge items that should be identify was calculated using equation (2) and resulted in as high as 95%. Recall is higher than precision and shows that the HoROnt knowledge base has a high degree of relevant entities signifying its completeness:

$$Recall = \frac{No\ of\ correct\ recommended\ items}{No\ of\ relevan\ recommended\ items} \tag{2}$$

F-measure provides a way to combine both precision and recall in a single score; it is calculated via equation (3). The F-measure of the algorithm was calculated as 0.92, which signifies a high degree of accuracy exhibited by the developed ontology:

$$F - measure = 2 * \frac{P * R}{P + R} \tag{3}$$

Figure 7 shows the precision, recall and F1 scores of the developed ontology.

A validation of the knowledge base was also realized by adding individuals (instances of concepts) to evaluate the completeness of axioms, properties and classes modeled in HoROnt. To this end, Ontology Pitfall scanner (OOPs!), a tool that detects errors according to a pitfall catalog including 41 common types of errors that occur during ontology development (Poveda-Villalón *et al.*, 2014) was used. The first time OOPs! was run, a total of 12 types of pitfalls were detected (Figure 8), including four critical pitfalls (P06, P19, P29 and P31), three important pitfalls (P11, P30 and P41) and five minor pitfalls (P04, P07, P03, P13 and P22). Pitfalls were corrected starting with the critical ones that affect the ontology reasoning, then the important pitfalls, which are not critical for ontology functioning, and finally the minor pitfalls. Upon completion of the correction process and re-evaluating the developed ontology, one minor pitfall remained, i.e. OOPs asserted that a toilet could be equivalent to a bathroom. According to the understanding of the researchers and domain experts, a toilet could not be equivalent to a bathroom, in the hotel room domain, and so it was ignored.

6. Related works

6.1 Ontology modeling

The assumption in using ontology as a foundation for conceptual modeling is that ontology can help us to understand the real world (Wand and Weber, 2006). An ontology is a formal, explicit specification of a shared conceptualization (Studer *et al.*, 1998). This implies that an

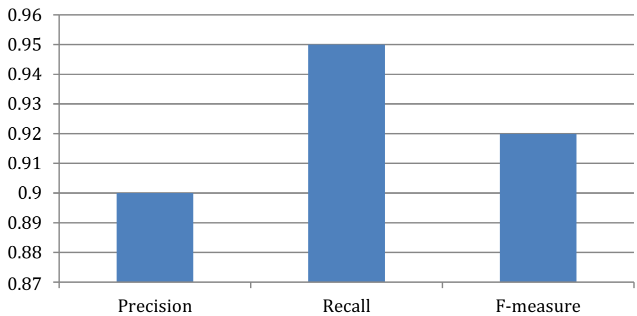

Figure 7.
Scores for of the hotel room personalization framework

- **Critical** : It is crucial to correct the pitfall. Otherwise, it could affect the ontology consistency, reasoning, applicability, etc.
- **Important** : Though not critical for ontology function, it is important to correct this type of pitfall.
- **Minor** : It is not really a problem, but by correcting it we will make the ontology nicer.

[Expand All] | [Collapse All]

Results for P04: Creating unconnected ontology elements.	3 cases | Minor
Results for P06: Including cycles in a class hierarchy.	1 case | Critical
Results for P07: Merging different concepts in the same class.	1 case | Minor
Results for P08: Missing annotations.	283 cases | Minor
Results for P11: Missing domain or range in properties.	19 cases | Important
Results for P13: Inverse relationships not explicitly declared.	11 cases | Minor
Results for P19: Defining multiple domains or ranges in properties.	3 cases | Critical
Results for P22: Using different naming conventions in the ontology.	ontology* | Minor
Results for P29: Defining wrong transitive relationships.	2 cases | Critical
Results for P30: Equivalent classes not explicitly declared.	1 case | Important
Results for P31: Defining wrong equivalent classes.	1 case | Critical
Results for P41: No license declared.	ontology* | Important

Figure 8.
Pitfalls generated by OOPs!

ontology captures consensual knowledge in a domain of interest for the development of credible knowledge-based information services and opens possibilities of reuse. Ontology presents concepts and relationships in a high level of abstraction, providing rich semantics for both humans and computers (Maria *et al.*, 2007; Di Noia *et al.*, 2018), thereby enabling computers and other digital systems to act based on an understanding of the information they are handling. Ontologies offer a myriad of benefits (Mishra and Jain, 2020), which make them appropriate for personalizing the hotel room, including: enabling of computational inference, which is useful for deriving implicit facts; making domain knowledge explicit through structuring and organizing knowledge; and furnishing mechanisms that support interoperability of systems.

A domain ontology provides basic knowledge about a particular domain of discourse that is necessary for problem understanding and presentation (Bogumiła *et al.*,2016). The hotel room domain semantically represents individual room amenities, the guest and his contextual variables. It is a data-rich domain where data is stored in disparate sources. Furthermore, it is a preference-based domain where people's choices about and uses of services are mainly guided by what they like and are interested in. However, to the best of our knowledge, there exists only one hotel room ontology RoomFort (Spoladore *et al.*, 2018), which focuses on modelling guest comfort metrics using sensors data.

6.2 Ontological-based reasoning

Ontologies describe categorizations of entities based on fundamental properties or characteristics (Hoehn *et al.*, 2019), and its capabilities allow for reasoning due to the formal and logic-based specifications in the information model (Qiao *et al.*, 2018). Ontological reasoning supports inferences such as high-level semantics, satisfiability and consistency which have favored its application across a variety of domains.

In the design domain, Das and Swain (2022) designed an ontology-based knowledge framework for identifying the appropriate assembly joining process to support designers and process planners, thereby ending up with a five-step sequential procedure for automatically selecting the joining process from the CAD model. In the education sector, Padilla-Cuevas *et al.* (2021) developed an ontological-based system for managing the academic context to represent events and reasoning with context information in academic advising, and academic course delivery. Another ontology-based system is Do-Care, a health-care monitoring system for patients with chronic diseases that uses a SWRL rule base to support the supervision and follow-up of outdoor and indoor patients suffering from chronic diseases (Elhadj *et al.*, 2021). In the tourism domain, Stathopoulos *et al.* (2020) present an ontology-based framework for capturing and interlinking assets of cultural and natural substances facilitating the formation of routes through spatial-temporal rule-based reasoning.

In this paper, ontological reasoning is used to explicitly express hotel room concepts and implicit relations to process complex domain information and offer personalized hotel room services.

6.3 Ontology-based personalization of accommodation systems

The hotel room domain is a preference-based domain where people's choices about and uses of services are mainly guided by what they like and are interested in; therefore, personalization can play a big role in ensuring customer satisfaction, and, in turn, the hotel's success. To provide the desired user-centric items during personalization, recommender systems are used. Recommender systems are the mechanisms behind personalization systems as they aim to predict user preferences or specific items (Tan and He, 2017;

Thendral and Valliyammai, 2018). They usually provide users with a sorted personalized item recommendation list based on the users historical preferences and constraints (Aljunid and Huchaiah, 2021). Popular recommendation techniques include: collaborative filtering, content-based recommenders, demographic algorithms; knowledge-based recommendation algorithms; and hybrid recommendation systems. Collaborative filtering approaches collect a person's historical data, such as system interactions and provide recommendations based on similarities with other users (Skillen *et al.*, 2013). They provide a quick and straightforward approach but suffer from the cold start problem (due to very little data available related to the user or item) and privacy issues. Demographic recommenders assume that different suggestions should be generated for different demographic niches (Ricci, 2002), making them stereotypical. Content-based filtering recommends new items similar to user's favorable items by extracting content features (Lian and Hui, 2014). However, finding similar items may not be that obvious (Barros *et al.*, 2021), not only for new users; besides, problems of overspecialization may arise, as the set of recommended items may be too homogeneous. Knowledge-based recommenders use experts' knowledge of the guest and his or her interactions, as well as hotel room knowledge, avoiding the cold-start problem. Ontologies, being the formal models of shared conceptualizations, are able to effectively model the needed knowledge (Agarwal *et al.*, 2022). They provide an effective way to model the user profile, to analyze preferences and needs at different levels of abstraction and inferences are used to reason about the preferences and needs on all the domain concepts (Borràs *et al.*, 2012). Knowledge-based recommender systems, being semantic in nature, are currently applied in many recommendation systems due to their effectiveness in providing item recommendations (Javed *et al.*, 2021). Ontologies alone, however, cannot represent all the knowledge in a domain and are thus enriched by rules, as we propose for our hotel room personalization or other methods such as machine learning techniques to obtain high-level expressiveness and produce new facts for applications such as personalization.

There are not many studies that have explored combining ontology-based systems and semantic rules to provide personalization in the accommodation domain. Among them, we can cite the personalized Hotel Search System, that consists of a hotel domain ontology, a question- and answer-based requirements collector and an hotel search interface (Yoo, 2012). Requirements are formatted into rules, while a query processing technique that combines a query rewriting method and additional reasoning knowledge is used for the search, providing a quick response time. Ontologies are also used in E-Cabin, a comfort optimization framework for IoT-equipped smart cruise ships (Nolich *et al.*, 2019). E-Cabin integrates a passenger ontology, a sensor and devices ontology and a comfort metrics ontology to constitute a framework's knowledge base used to support querying and reasoning activities. SWRL rules are used to solve queries at real-time and to enable modification of query patterns, thereby ensuring customization of passenger's comfort metrics. E-Cabin can turn an IoT-equipped environment into an automatic system capable of adapting the environment to the personalized comfort needs of every user. RoomFort, a system that aims at providing guests with comfort metrics that are tailored to their comfort needs developed by Spoladore *et al.* (2018), is the closest to the framework proposed in this paper. RoomFort was developed using semantic web standards and reasons over data stored in a private cloud repository. It focused on comfort metrics defined for business travelers by reusing SAREF, Acco and DogOnt ontologies and the International Classification of Functioning, Disability and Health ontology.

Even though previous works in the hotel room domain improved personalization in the hotel and other accommodation facilities, they majorly focused on comfort metrics or specific categories of guests. They did not consider other guests needs and preferences to offer a comprehensive personalized service. Given that the hotel room domain cannot afford to continue being fragmented, HoROnt plays a big role of collating all the domain information into a single knowledge base that facilitates communication, consensus and alignment. Using rules written in SWRL, new facts that are not expressible in the ontology can be deduced and relevant instances linked to them, and the cold start problem is reduced.

7. Conclusion and future work

This paper describes a hotel room personalization framework based on a domain ontology, HoROnt, and rule-based formalisms to provide personalized hotel room services and features. The goal is to be able to recommend the right hotel room services and amenities to the guest at the right time. The framework uses knowledge on room characteristics and guest profiles to activate SWRL rules. The semantic rules allow the inference engine to give recommendations to personalize hotel rooms. Combining different kinds of hotel room domain knowledge for provision of services and hotel features based on guests' characteristics and preferences, the framework solves issues of semantic inconsistencies, cold start and ambiguities by performing a detailed analysis of guests' profiles before recommending hotel room services and amenities.

The implications of the study are as follows. First, the work adds value to the field of domain ontologies dedicated to the representation of knowledge necessary to customize amenities and services within a hotel room. It can be used as a guide in developing similar ontologies as the core ontology, HoROnt, is publicly available. Secondly, the study contributes to the state-of-art in recommender systems by offering a hotel room personalization framework that exploits ontology and a rule base for knowledge representation so that an inference engine can be used to suggest personalization options for hotel rooms. Thirdly, the framework can inform and guide hotel managers and owners on the terms that they need to adopt to effectively describe hotel room features and amenities on their websites. This would serve to improve a hotel website's content while presenting customers with appropriate information, supporting marketing and advertising activities. Finally, thanks to the standards adopted to implement it, the framework can be integrated into hotel information systems and booking platforms. It can also be adapted for any type of accommodation since it is broad-based and personalizes varying features and amenities in the rooms. On the other hand, a key challenge for the proposed framework is that of privacy, associated with sensitive data being accessible by all using the systems. In future, the developed personalized system can be enhanced to support privacy awareness for the fulfillment of hotel and guest's security needs.

The following are prospective points for future study:

- Extend HoROnt and its rule set to be used in the development of other ontologies within the hospitality sector, such as AirBnB and cruises.
- Create versions of the ontology in languages other than English to encourage its adoption.
- Integrate the rule-based framework with machine learning algorithms such as deep-learning techniques to further improve the personalization of services within the hotel room.
- Design personalized systems complying with privacy and security regulations, a challenging goal for ontology-based systems.

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