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Design and Evaluation of an Ontology-Based Context-Aware System for Advertising Recommendations

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***Abstract*— This research focuses on the design and evaluation of an ontology-based context-aware system for advertising recommendations. The study addresses the limitations of traditional advertising systems, which often neglect key contextual factors such as user location, time, and needs. Using the NeOn methodology, the proposed ontology incorporates these contextual dimensions, integrating widely accepted ontologies like FOAF, OWL-Time, and WGS84 Geo Positioning. The developed ontology was tested using SPARQL and GeoSPARQL queries to ensure it could accurately represent advertising and contextual information, delivering relevant recommendations tailored to users' current situations. The results demonstrate the ontology's scalability, expressiveness, and effectiveness in providing context-aware advertising recommendations. Future work includes developing a mobile application that leverages the ontology to enhance real-time advertising recommendations.**

Keywords*— Ontology-based system; Context-aware advertising; NeOn methodology; SPARQL/GeoSPARQL queries; Recommendations.

I. INTRODUCTION

Technological advancements have led to widespread use of mobile devices to support a growing range of activities, regardless of time or place. We are now witnessing a transition from the era of personal computers to a new phase called ubiquitous computing. The goal of ubiquitous computing is to integrate smart devices and applications into all aspects of human life.

Within this field, one of the most important areas for researchers is context-aware computing. This aims to equip applications with knowledge about their environment so they can adapt and offer relevant information or services based on the user's current situation.

However, many applications, particularly recommendation systems, often overlook key contextual factors like location, time, and user needs when making recommendations. This is particularly problematic in mobile environments, such as when users receive overwhelming amounts of irrelevant advertising content, leading to dissatisfaction. To address this, new efforts have emerged to expand recommendation systems to include context, creating multidimensional models (user x item x context), known as context-aware recommendation systems.

Modeling contextual knowledge is both crucial and challenging in developing these systems, as traditional methods and tools are not suitable for representing context. A comparative study analyzed several approaches—such as key-value pairs, markup schemes, graphs, object-oriented methods, logic-based models, ontologies, and machine learning [1]. The study concluded that ontology-based approaches are the most effective for representing context due to their formalism, scalability, and semantic richness.

This paper aims to describe the process of building an ontology to represent both advertisement information and the context in which it should be recommended, using the NeOn methodology [2]. The contextual dimensions considered include location, time (weekday, weekend, morning, afternoon, evening, night), and the type of user need (food, sports, entertainment, etc.).

To achieve this, Section 2 presents a brief review of related work. Section 3 details the methodological steps taken to build the context-aware advertising ontology. Section 4 describes the resulting model and a test scenario used to evaluate the ontology. In Section 5, the study results are compared with other related work. Finally, Section 6 presents conclusions and future research directions.

II. Review of Approaches and Applications

Ontology-based context modeling has been the focus of several studies in the field of context-aware computing. One of the first works in this area was COBRA-ONT [3], which consists of a network of ontologies that provides a vocabulary to model physical locations, characterize software agents and people, and describe their location in time as well as the events they are involved in.

A more comprehensive model is SOUPA [4], which supports interoperability and scalability through the reuse of various ontologies. SOUPA is divided into two parts: SOUPA CORE and SOUPA EXTENSION. The CORE includes a generic vocabulary built from widely accepted ontologies, such as:

- FOAF to describe contact information and user profiles;
- DAML Time, now known as OWL-Time, to model time and temporal properties of entities;
- OpenCyc and OpenGis for physical and symbolic space representation;
- COBRA-ONT for modeling context in smart meeting rooms;
- MoGATU BDI for modeling users' beliefs, desires, and intentions.

SOUPA EXTENSION allows the vocabulary to be expanded for use in specific domains.

Another conceptually defined model is CONON [5], which includes a high-level context ontology with generic concepts such as person, location, activity, and computational entity. New ontologies can be extended from these concepts to add domain-specific ideas.

CACont [6] is an ontology written in Web Ontology Language (OWL) with a hierarchical structure similar to CONON. It includes:

- User, reusing FOAF to describe user profiles, along with user agendas, calendars, events, and activities;
- Device, modeling the characteristics of devices around the user;
- Service, showing the services available to the user based on their context;
- Space, describing user location via geographical coordinates or symbolic representation;
- Environment, describing physical conditions such as temperature, humidity, and noise.

The mIO Proposal [7], also built in OWL, uses a modular design that allows ontologies to be added or removed according to domain needs. It includes ontologies for users (FOAF), roles, time (OWL-Time), location (SOUPA), environmental conditions, context sources, services, and devices.

After analyzing these models for context description, it can be concluded that most use a top-down strategy. This involves a high-level layer with generic concepts that represent contextual dimensions, such as person, place, time, and activity. From these concepts, widely accepted and shared ontologies like FOAF and OWL-Time are derived and reused to represent each dimension of context in detail.

An additional approach worth mentioning is WGS84 Geo Positioning [8], which has a simple structure for representing the location of entities with spatial characteristics using geographical coordinates (latitude, longitude, and altitude).

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In terms of research focused on incorporating contextual knowledge into advertising recommendations, most studies have concentrated on domains like interactive television (iTV) and contextual web advertising. These works primarily use traditional modeling methods (key-value, markup schemes, graphs, object-oriented), or data mining and machine learning techniques. Only a few use ontology-based semantic technologies.

For example, A personalized advertising system was developed to model the semantic relationships between iTV content and recommended ads, showing improvements over previous approaches that relied solely on quantitative content data using collaborative filtering techniques [9]. Another study introduced an ontological model to represent users' TV consumption habits [10]. Additionally, an intelligent keyword management system was proposed, utilizing ontologies to search and recommend contextual web advertisements [11]. A web-based car advertisement system architecture was also designed, employing an ontology to establish the semantic relationships between ads and user interests, overcoming the limitations of text mining techniques in cases where identical keywords are not present [12].

In mobile applications, a notable context-aware advertising recommendation system was developed, utilizing a modified collaborative filtering algorithm based on machine learning. This system integrates contextual dimensions such as location, time, and user-specific needs to deliver more relevant advertisements [13].

III. METHODOLOGY

To develop the context-aware ontology for advertising recommendations, a top-down approach was used, following the guidelines of the NeOn methodology. Specifically, scenario six was applied, which involves reusing, merging, and reengineering existing ontological resources. This approach made it possible to take advantage of commonly shared concepts from several widely used ontologies within the scientific community. These were combined into a new ontology model, along with additional concepts specific to the advertising and context domains, such as location, time, and user needs, for which the recommendations are intended. This required a process of ontological reengineering.

A. Ontology Requirements Specification

In this step, the functional and non-functional requirements that the ontology must meet were defined. A template provided by the NeOn methodology [14] was utilized to accomplish this. Table 1 presents the first five sections of the Ontology Requirements Specification Document (ORSD).

TABLE I. REQUIREMENTS SPECIFICATION DOCUMENT: SECTIONS 1 TO 5

Section	Description
1. Objective	The objective is to create an ontological model that represents advertising information and the relevant contextual dimensions. This model aims to ensure that advertisements are personalized and relevant to the end user.
2. Scope	The ontology will model the key entities involved in the advertising recommendation process, such as citizens, advertisers, locations/points of interest, and products/services. It will also capture contextual features such as location, day of the week (weekday, weekend), time of day (morning, midday, afternoon, night), and the type of user need (e.g., food, sports, entertainment) for effective advertisement dissemination.
3. Implementation Language	The ontology will be developed using OWL and hosted in an open repository.
4. End Users	Advertisers and citizens.
5. Intended Use	The ontology will be integrated into a mobile, context-aware advertising recommendation system, enhancing the experience for advertisers and users by delivering personalized and contextually relevant advertisements.

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To determine the functional requirements, the competency questions technique was used. This involves writing a set of natural language questions that the ontology should be able to answer. Table 2 presents section six of the ORSD, which lists both the functional and non-functional requirements.

TABLE II. REQUIREMENTS SPECIFICATION DOCUMENT: SECTION 6

Section	Details
Non-Functional Requirements	- The ontology must be developed using standards and ontological models that are widely recognized and shared within the scientific community. - The ontology should be structured into two layers: - **Upper Layer:** Includes generic classes and properties applicable to any domain. - **Lower Layer:** Incorporates classes and properties specific to the domain of advertising.
Functional Requirements – Competency Questions	**1. What are the geographic coordinates of the point of interest 'Rabat Marina'?** - Latitude: 34.027542, Longitude: -6.836396. **2. Which nearby locations or points of interest (within 1 km) are close to the user's current location in Rabat?** - Café Maure: Avenue Hassan II - Oudayas Beach: Rue des Consuls - Kasbah des Oudayas: Avenue de la Victoire **3. What advertisements are offered by 'Café Maure'?** - Traditional Moroccan mint tea - Assorted Moroccan pastries **4. Which products are promoted in the ads from 'Dar Moha Restaurant'?** - Moroccan tagine, couscous, desserts **5. What advertisements are being promoted at 'Oudayas Beach' during the weekend afternoons?** - Surfing lessons available, 3:00 PM - 5:00 PM - Sunset yoga classes, 5:00 PM - 7:00 PM **6. Which ads meet the user's food needs on a weekday at midday in Casablanca?** - Al Mounia: Traditional Moroccan lunch - Rick's Café: International cuisine, lunch specials **7. What are the user's preferences for weekend night ads in Marrakech?** - Food, traditional music, art galleries **8. Which ads should be recommended to the user based on their location (latitude: 31.629472, longitude: -7.981084, within 1 km), current time (weekend, at night), and needs (food, music, culture)?** - 'Jemaa el-Fna Square: Enjoy live Gnawa music and Moroccan street food' - 'La Maison Arabe: Traditional Moroccan dinner with live music'

The final section of the ORSD is a pre-glossary of terms extracted from the competency questions and their answers, using simple heuristic methods for terminology extraction. The aim is to identify nouns, adjectives, and verbs that will be represented in the ontology as concepts, attributes, relationships, or instances. Table 3 provides the pre-glossary of terms along with their frequency of occurrence.

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TABLE III. REQUIREMENTS SPECIFICATION DOCUMENT: SECTION 6

a- Terms from Competency Questions	
Advertisement (6)	Product (1)
User, citizen (4)	Preference (1)
Nearby (1)	Promotion (2)
Coordinate (1)	Satisfy (1)
Distance (2)	Recommend (1)
Locality, point of interest (2)	Need (2)
Location (3)	Day (1)
Latitude (1)	Week (3)
Longitude (1)	Time (1)
Advertising organization (1)	Schedule (3)
b- Terms from Answers to Competency Questions	
Address (3) Latitude (2)	Longitude (2)
c- Objects	
31.629472, -7.981084, ... 1 kilometer, ... 15:00-17:00, 16:00-18:00, ... Food, sports, cinema, entertainment, ... Avenue Mohammed V and Rue Hassan II, Avenue des Far and Rue Soukaina, ... Beverages, Moroccan dishes, desserts, ... Traditional mint tea, Lamb tagine with prunes, Premiere of the movie "Casablanca," Movie "Hassan and Morjana," 2 for 1, ... Jemaa el-Fna, Café Maure, McDonald's, Dar Moha Restaurant, Rick's Café, ... Weekend, weekday, ... Afternoon, midday, night, ...	

B. Ontology Modeling and Implementation

Based on the pre-glossary of terms, the conceptualization process was carried out to identify the concepts, attributes, and relationships to be included in the ontology. The NeOn methodology recommends using the most frequently appearing terms, but other relevant terms were also selected, such as "advertising organization," "product-service," "preference," and "need," to ensure that all the requirements defined in the ORSD were met. This section outlines the concepts included in the ontology, while the attributes and relationships are detailed in the results section.

- Citizen (person): Represents the identity and profile of individuals who receive advertising recommendations.
- Advertising organization: Represents the companies or institutions that promote their products or services through advertisements.
- Product-service: Describes the products or services promoted through advertisements by the advertising organizations.
- Point of interest (places): Describes the location of a place or point of interest using geographic coordinates (longitude and latitude) and symbolic representation (address).
- Advertisement: Represents the ads distributed or recommended to citizens by the advertising organizations.

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- Schedule: A temporal entity that describes the days of the week and the times when advertisements are broadcast.
- Preference: A temporal entity modeling the changing preferences of citizens over time in relation to their needs, such as food needs at midday and entertainment preferences at night.
- Need: Represents the types of needs users (citizens) have, which the advertisements must fulfill.
- Day of the week: Represents the seven days of the week, such as Monday, Tuesday, Wednesday, etc.
- Type of day of the week: Classifies the days of the week, for example, regular days (Monday to Friday) and weekend days (Saturday and Sunday).
- Type of schedule: Represents a classification of time slots, such as morning (07:00 - 12:00), midday (12:00 - 14:00), etc.

As mentioned, the goal of this work is to build a model using existing, widely accepted ontological resources used by a large part of the scientific community. Thus, activities such as searching, comparing, and selecting ontological resources, as well as subsequent tasks of merging and reengineering the selected resources, were necessary to adapt them to the specific needs of the domain being studied.

Ontology resource search: The search focused on the concepts previously identified, using semantic search engines like Watson and Swoogle. Additionally, manual searches were conducted in ontology repositories such as Protégé Ontology Library, UbisWorld, and Linked Open Vocabularies (LOV), among others. The candidate ontologies found are described in the related work section.

Comparison and selection of ontologies: The comparative analysis of the candidates was based on four dimensions: reuse cost, ease of understanding, effort required for integration with the model to be developed, and the reliability of the ontology. Based on this analysis, the selected ontologies were:

- FOAF to represent the profiles of advertising organizations and citizens, reusing the classes "Organization" and "Person";
- OWL-Time to model the temporal properties of entities related to citizens' changing preferences and advertisement schedules, reusing the classes "TemporalEntity," "DayOfWeek," "Instant," and "GeneralDateTimeDescription";
- WGS84 Geo Positioning for its simple structure, which includes all the necessary concepts and relationships to represent the physical location (geographic coordinates) of entities in the study domain. The main class "SpatialThing" was used, along with key properties such as "Latitude" and "Altitude."

Merging and customizing the selected ontologies: To adapt the selected resources to the requirements of the ORSD, the following steps were necessary:

- Manually align and merge the ontologies by creating relationships and correspondences between the entities from different ontologies;
- Prune the reused ontologies according to the ORSD requirements, removing irrelevant concepts in some cases;
- Enrich the reused ontologies by creating new conceptual structures to meet the ORSD requirements, such as adding the "category" property to classify advertising organizations;
- Adapt the selected ontologies to the design criteria of the target ontology by renaming reused concepts to match the naming conventions and meanings specified in the ontology. All selected ontologies were available in RDF or OWL, so no translation of the implementation language was required.

In parallel with the merging and reengineering activities, additional concepts, relationships, and attributes specific to the domain of advertising and the context, which could not be reused from existing ontological resources, were included.

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C. *Ontology Evaluation*

The goal of this activity was to validate that the developed ontology is capable of representing both the advertisement information and the contextual data required for making recommendations. To achieve this, several test scenarios were modeled and instantiated based on the competency questions from the ORSD. Then, SPARQL [15] and GeoSPARQL [16] queries were applied to ensure that the ontology could provide answers to the ORSD questions. In some cases, adjustments were made to the conceptual structure due to identified errors or missing information. The following section describes one of the test scenarios used for this evaluation.

IV. RESULTS

As a result of the described methodology, Table 4 and Table 5 provide a description of the ontology's object properties (ObjectProperty) and data properties (DatatypeProperty), respectively. Additionally, Fig. 1 presents the metamodel of the context-aware ontology for recommending advertisements. Additionally,

TABLE IV. LIST OF OBJECT PROPERTIES IN THE ONTOLOGY

Domain	ObjectProperty	Range
Citizen	hasInterestIn: describes a citizen's interest in an advertisement. Inverse property: interests.	Advertisement
Citizen	expresses: represents the evolution of a citizen's needs over time. Inverse property: expressedBy.	Preference
Advertiser	offers: describes the portfolio of products or services offered by an advertiser. Inverse property: offeredBy.	Product/Service
Advertiser	recommends: represents the action of recommending an advertisement by an advertiser. Inverse property: recommendedBy.	Advertisement
Advertiser	locatedAt: identifies the locations or points of interest where an advertiser is situated. Inverse property: locates.	Point of Interest
Advertisement	promotes: describes the products, services, or points of interest promoted by an advertisement. Inverse property: promotedAt.	Product/Service, Point of Interest
Advertisement	disseminatedAccordingTo: associates an advertisement with the types of days and times of dissemination. Inverse property: plansDisseminationOf.	Schedule
Advertisement	satisfies: specifies the needs satisfied by an advertisement. Inverse property: satisfiedBy.	Need
Preference	includes: represents the evolution of a citizen's needs over time. Inverse property: includedIn.	Need
DayType, TimeType	hasSubNeed: represents a hierarchical typology of needs. For example: sports can include more specific needs like football, basketball, etc.	Need
Schedule	includes: represents the type of day and time when an advertisement is broadcasted. Inverse property: includedIn.	DayType, TimeType
DayType	categorizes: classifies or groups the days of the week. Inverse property: categorizedIn.	Weekday (equivalent class with OWLTime)

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TimeType	startTime: represents the time from which an advertisement can be broadcasted. OWLTime	TimeType
TimeType	endTime: represents the time until which an advertisement can be broadcasted. OWLTime	TimeType

TABLE V. LIST OF DATATYPE PROPERTIES IN THE ONTOLOGY

Class	DatatypeProperty
Citizen (subclass of foaf)	• **username (foaf)**: the user's account name. • **firstName (foaf)**: the citizen's first name. • **lastName (foaf)**: the citizen's last name. • **age (foaf)**: the citizen's age. • **gender (foaf)**: the citizen's gender. • **email**: the citizen's email address. • **mobilePhone**: the citizen's mobile phone number.
AdvertiserOrganization (subclass of foaf)	• **businessName**: the name of the organization. • **category**: the type of organization, for example: restaurant, cinema, supermarket, etc.
ProductService	• **name**: name of the location or point of interest. • **address**: symbolic description of the point of interest's location (main street, secondary street, and number). • **latitude** (wgs84), **longitude** (wgs84): geographic coordinates of the location.
PointOfInterest (Subclass of WGS84)	• **message**: content of the advertisement message.
Advertisement	• **name**: generic name of the product or service. • **description**: descriptive information about the product or service (brand, model, characteristics, etc.).
Need	• **name:** type of need, for example: food, clothing, entertainment, sports, etc.
DayType	• **name:** type of day, for example: weekday, weekend day, etc.
DayOfWeek	• **name:** name of the day, for example: Sunday, Monday, Tuesday, etc. • **DayNumber:** numerical assignment that identifies and orders the days of the week, for example: 0 – Sunday, 1 – Monday, 2 – Tuesday, etc.
TimeType (subclass of OwlTime)	• **name:** type of schedule, for example: morning (07:00 - 12:00), midday (12:00 - 14:00), etc.

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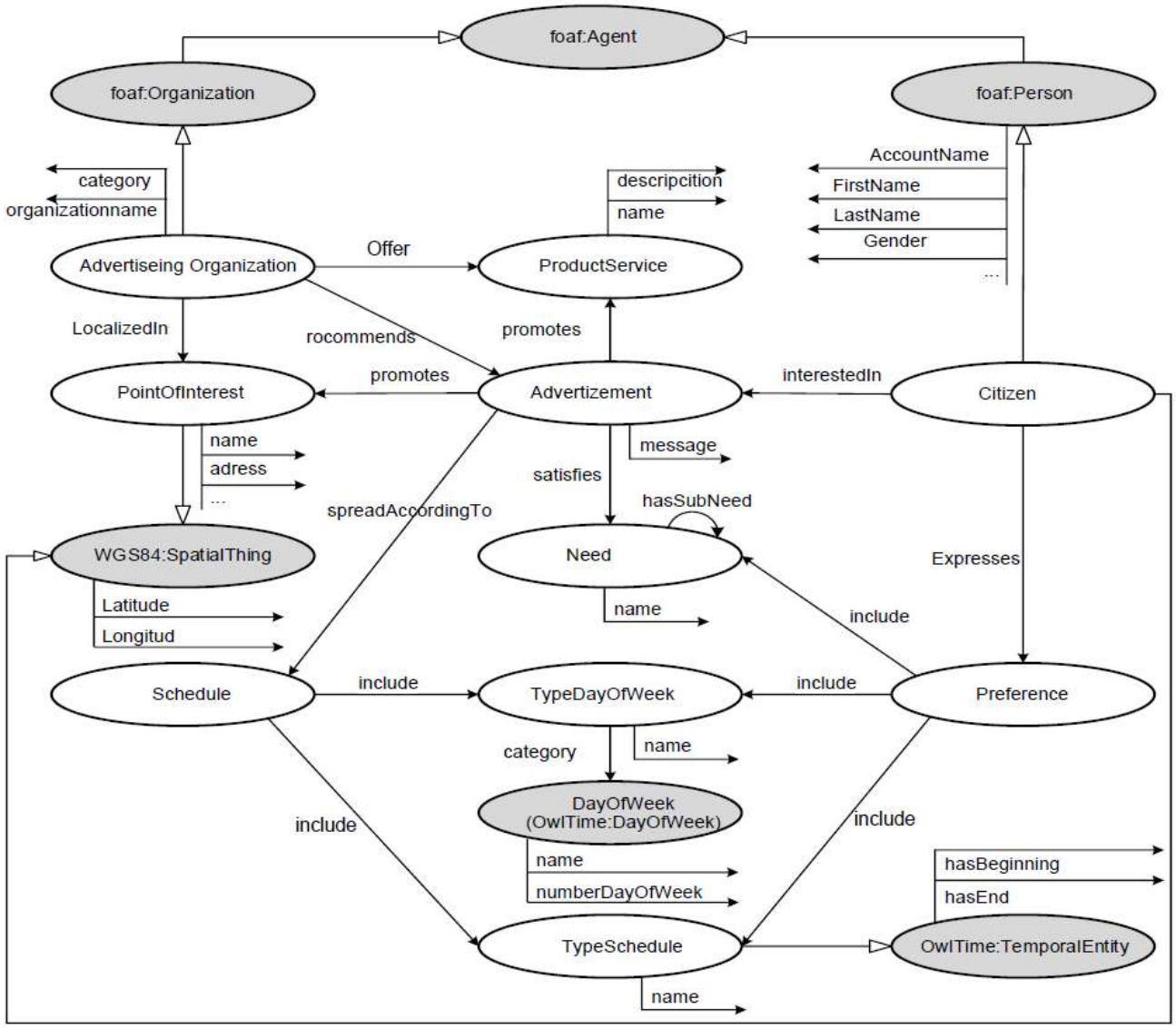

Fig. 1. Metamodel of the Context-Aware Ontology for Recommending Advertisements.

To demonstrate the results of the ontology evaluation, one of the test scenarios is described below. It includes the ontological representation, the specification of the query using SPARQL and GeoSPARQL, and the recommendations obtained from the query's execution.

The proposed scenario was based on question eight from the ORSD and involves a user named Rachid ED, located at geographic coordinates: latitude 31.62947 and longitude -7.981084, on a Saturday night. The user has previously indicated preferences for weekend evenings, such as dining out, watching sports, or going to the movies. Additionally, the Sports Planet restaurant and Ciné Atlas Marrakech, both located within one kilometer of the user's current location, require that advertisements be displayed to users with similar preferences. The ads would promote “Enjoy football with a delicious dinner” and “2 x 1 on movies,” respectively. Figure 2 shows the ontological representation of this scenario in TURTLE format.

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```
@base <http://www.ontologies.com/ContextAwareAds> .
@prefix ads: <http://www.ontologies.com/ContextAwareAds#> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix foaf: <http://xmlns.com/foaf/0.1/> .
@prefix time: <http://www.w3.org/2006/time#> .
@prefix geo: <http://www.w3.org/2003/01/geo/wgs84_pos#> .
<http://www.ontologies.com/ContextAwareAds> rdf:type owl:Ontology ;
owl:imports foaf: , time: , geo: .

ads:rachid rdf:type owl:NamedIndividual , ads:Citizen ;
foaf:username "rachid.ed" ;
foaf:firstName "Rachid" ;
foaf:lastName "Ed" ;
foaf:gender "Male" ;
foaf:age 35 ;
geo:latitude 31.629472 ;
geo:longitude -7.981084 ;
ads:expresses ads:weekendEveningPreference .
ads:weekendEveningPreference rdf:type owl:NamedIndividual , ads:Preference ;
ads:includes ads:eating , ads:sports , ads:cinema , ads:weekend , ads:evening .

ads:eating rdf:type owl:NamedIndividual , ads:Need ;
ads:name "eating" .
ads:sports rdf:type owl:NamedIndividual , ads:Need ;
ads:name "sports" .
ads:cinema rdf:type owl:NamedIndividual , ads:Need ;
ads:name "cinema" .

ads:weekend rdf:type owl:NamedIndividual , ads:DayType ;
ads:name "weekend" ;
ads:categorizes ads:saturday , ads:sunday .
ads:saturday rdf:type owl:NamedIndividual , ads:Weekday ;
ads:name "Saturday" ;
ads:dayNumber "6" .
ads:sunday rdf:type owl:NamedIndividual , ads:Weekday ;
ads:name "Sunday" ;
ads:dayNumber "0" .

ads:evening rdf:type owl:NamedIndividual , ads:TimeType ;
ads:name "evening" ;
time:hasBeginning ads:eveningStartTime ;
time:hasEnd ads:eveningEndTime .
ads:eveningStartTime rdf:type owl:NamedIndividual , time:Instant ;
time:inDateTime ads:eveningStartDescription .
ads:eveningStartDescription rdf:type owl:NamedIndividual , time:GeneralDateTimeDescription ;
time:hour 19 ;
time:minute 0 .
ads:eveningEndTime rdf:type owl:NamedIndividual , time:Instant ;
time:inDateTime ads:eveningEndDescription .
ads:eveningEndDescription rdf:type owl:NamedIndividual , time:GeneralDateTimeDescription ;
time:hour 24 ;
time:minute 0 .

ads:sportPlanet rdf:type owl:NamedIndividual , ads:PointOfInterest ;
ads:name "Sports Planet Restaurant" ;
ads:address "Avenue Mohammed V and Rue Hassan II" ;
geo:latitude 31.629012 ;
geo:longitude -7.980450 .
ads:cineAtlas rdf:type owl:NamedIndividual , ads:PointOfInterest ;
ads:name "Ciné Atlas Marrakech" ;
ads:address "Avenue des Far and Rue Soukaina" ;
geo:latitude 31.630089 ;
geo:longitude -7.980112 .
```

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```
67: ads:ad1 rdf:type owl:NamedIndividual , ads:Advertisement ;
68: ads:message “Enjoy football while savoring a delicious meal” ;
69: ads:promotes ads:sportPlanet ;
70: ads:satisfies ads:eating , ads:sports ;
71: ads:disseminatedAccordingTo ads:weekendEveningSchedule .
72: ads:ad2 rdf:type owl:NamedIndividual , ads:Advertisement ;
73: ads:message “2-for-1 on movies” ;
74: ads:promotes ads:cineAtlas ;
75: ads:satisfies ads:cinema ;
76: ads:disseminatedAccordingTo ads:weekendEveningSchedule .
77: ads:weekendEveningSchedule rdf:type owl:NamedIndividual , ads:Schedule ;
78: ads:includes ads:weekend , ads:evening .
```

Fig. 2. Ontological representation of the test scenario in TURTLE format.

Lines 1 and 2 specify the namespace and prefix of the created model, while line 9 defines it as an ontology. Lines 3 to 8 declare the namespaces and prefixes of the reused ontologies, and line 10 imports FOAF, OWL-Time, and WGS84 Geo Positioning ontologies. Lines 12 to 19 describe the identity and location details of the citizen Rachid ED and line 20 associates him with the instance "preferenceWeekendEvening," which defines his preferences for weekend evenings.

Lines 21 and 22 create the "preferenceWeekendEvening" instance as a type of preference, associating it with the instances that represent the needs for "dining," "sports," and "movies," as well as the temporal entities "weekend" and "evening." These needs are instantiated in lines 24 to 29. The categorization of "Saturday" and "Sunday" as weekend days is represented between lines 31 and 39, with a numerical identifier assigned to each day. The description of "evening" as a time slot starting at 19:00 and ending at 24:00 is provided between lines 41 and 54, using the Instant and GeneralDateTimeDescription classes, along with the inDateTime, hour, and minute properties from the OWL-Time ontology.

The representation of "Sports Planet Restaurant" and "Ciné Atlas Marrakech" as points of interest, along with their geographical locations (latitude and longitude), is provided between lines 56 and 65. Finally, the details of the advertisements—such as the message to be displayed, the point of interest being promoted, the needs fulfilled, and the broadcasting schedule—are shown between lines 67 and 78.

Based on the ontological representation of this test scenario, it is clear that the proposed ontology has a highly expressive conceptual structure, with a set of classes and properties that precisely and comprehensively meet all the requirements outlined in the scenario, especially those related to context dimensions like location, time, and user needs.

The ontology and its instances were stored on an Apache Jena Fuseki SPARQL server [17], configured to support geospatial queries through GeoSPARQL.

To confirm that the ontology could adequately answer question eight from the ORSD, which served as the basis for the test scenario, a query combining SPARQL and GeoSPARQL statements was constructed and executed. Table 6 presents the query that meets this requirement, along with the recommendations obtained, which align with the expected answers from the ORSD and are adjusted to the user's current context, as described in the test scenario (location: within 1 kilometer, time: weekend evening, needs: dining out, watching sports, or going to the movies).

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TABLE VI. QUERY SPECIFICATION AND RECOMMENDATIONS OBTAINED

Query with Sparql and GeoSparql Statements
1. PREFIX spatial: <http://jena.apache.org/spatial#>
2. PREFIX xsd: http://www.w3.org/2001/XMLSchema#
3. PREFIX ads: <http://www.ontologies.com/ContextAwareAds#>
4. PREFIX foaf: http://xmlns.com/foaf/0.1/
5. PREFIX time: http://www.w3.org/2006/time#
6. PREFIX geo: <http://www.w3.org/2003/01/geo/wgs84_pos#>
7.
8. SELECT ?message ?poiName ?needName ?dayTypeName ?timeTypeName
9. WHERE {
10. ad ads:message ?message .
11. poi ads:name ?poiName .
12. need ads:name ?needName .
13. dayType ads.name ?dayTypeName .
14. timeType ads.name ?timeTypeName .
15.
16. user foaf:username ?userName .
17. user ads:expresses ?preference .
18. preference ads:includes ?need .
19. ad ads:satisfies ?need .
20.
21. poi spatial:nearby(31.629472 -7.981084 1 'kilometer') .
22. ad ads:promotes ?poi .
23.
24. preference ads:includes ?dayType .
25. dayType ads:categorizes ?Day .
26. Day ads:dayNumber ?dayNumber .
27.
28. preference ads:includes ?timeType .
29. timeType time:hasBeginning ?startTime .
30. startTime time:inDateTime ?startDescription .
31. startDescription time:hour ?startHour .
32. startDescription time:minute ?startMinute .
33. timeType time:hasEnd ?endTime .
34. endTime time:inDateTime ?endDescription .
35. endDescription time:hour ?endHour .

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```
36. endDescription time:minute ?endMinute .
37.
38. ad ads:disseminatedAccordingTo ?adSchedule .
39. adSchedule ads:includes ?dayType .
40. adSchedule ads:includes ?timeType .
41.
42. BIND (day(xsd:date(now()) - xsd:date("1900-01-01-05:00"))+1 AS ?days) .
43. BIND (?days - floor(?days/7)*7 AS ?currentDayNumber) .
44.
45. FILTER (?userName = "rachid.elm" &&
46. ?dayNumber = ?currentDayNumber &&
47. ((hours(now())*60 + minutes(now())) >= (?startHour*60 + ?startMinute) &&
48. (hours(now())*60 + minutes(now())) <= (?endHour*60 + ?endMinute)))
49. }
```

Advertisement	Point of Interest	Need	Day Type	Time Type
"Enjoy football while savoring a delicious meal"	Sports Planet Restaurant	Eating, Sports	Weekend	Evening
"2-for-1 on movies"	Ciné Atlas Marrakech	Cinema	Weekend	Evening

The query structure in Table 6 is as follows:

- Lines 1 to 6 declare the namespaces and prefixes of the ontologies used in the query, with the "spatial" prefix referring to the GeoSPARQL vocabulary.
- Line 8 defines a SPARQL SELECT query that returns the variables: the advertisement message, the name of the point of interest, the need fulfilled, the type of day, and the time slot for broadcasting.
- Lines 9 to 49 establish the query's WHERE clause, defining the triple patterns or search criteria. These include context restrictions related to location, time, and user needs.
- Lines 18 and 19 filter the advertisements to include only those that meet the user preferences set by Rachid ED.
- Lines 21 and 22 use the "nearby" function from GeoSPARQL to filter advertisements promoting points of interest located within 1 kilometer of Rachid ED's current position.
- Lines 24 to 48 filter the advertisements to show only those broadcasted on the current day and time. Lines 42 and 43 calculate the day of the week (for example, 6 for Saturday), while lines 47 and 48 determine the current time slot.

In conclusion, the execution of this test scenario demonstrated that the proposed ontology is capable of providing relevant advertising recommendations based on the user's current context (location, time, and needs), as specified in the ORSD. Additional scenarios were also instantiated, giving similarly successful results.

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V. Discussion

As discussed in the related work section, most research proposals that incorporate contextual knowledge into advertising recommendation systems rely on traditional modeling methods, which often lack formality, expressiveness, and scalability. Others apply data mining and machine learning techniques, which focus primarily on quantitative information, with few efforts aimed at using ontology-based semantic technologies [18].

To address these limitations, this work has aimed to leverage the intrinsic advantages of ontologies, particularly their formalism and expressiveness. The developed ontological model accurately defines the semantic relationships between advertisements and contextual factors such as location, time, and user needs. As demonstrated in the test scenario, these relationships can be easily interpreted and processed using SPARQL and GeoSPARQL queries without losing their semantic meaning.

The use of a top-down strategy in building the ontology, combined with the flexibility of the NeOn methodology, has resulted in a highly understandable and scalable model. This model supports the reuse of widely accepted and validated ontologies like FOAF, OWL-Time, and WGS84 Geo Positioning, which have been applied in real-world scenarios. Additionally, the structure of this model allows for the integration of new concepts in the future with minimal effort and impact on existing elements.

One key feature that sets this ontological model apart from other approaches is its ability to infer implicit knowledge from the existing triples and constraints through the implementation of a reasoner

VI. Conclusions and Recommendations

In this work, various ontological approaches for representing context in mobile or ubiquitous computing systems were analyzed. It was concluded that most of these approaches share a similar structure, following a top-down strategy. This strategy is based on a set of generic concepts applicable to all domains, mainly representing key contextual dimensions (such as person, location, time, activity, etc.). From these concepts, widely used ontologies like FOAF and OWL-Time are derived and reused to model each contextual dimension in depth or to customize the model for a specific domain. Additionally, various approaches for context modeling in advertising recommendation systems were reviewed, with most focusing on domains like interactive television (iTV) and web-based contextual advertising. These methods primarily used traditional approaches or data mining and machine learning techniques, without considering important aspects for contextual information representation, such as formality, semantics, and extensibility.

To build the context-aware advertising ontology, a top-down approach was used, following the guidelines of the NeOn methodology and applying scenario six, which involves reusing, merging, and reengineering existing ontological resources. Through the activities of requirement specification and conceptualization, the key concepts to include in the ontology (such as citizen, advertising organization, product-service, point of interest, advertisement, schedule, preference, and need) were identified. These concepts guided the search and selection of ontological resources to be reused, minimizing the effort required to build an ontology from scratch. The result was an expressive and extensible ontological model that integrates FOAF, OWL-Time, and WGS84 Geo Positioning ontologies. For evaluation, a test scenario was created based on the questions from the ORSD, and by applying SPARQL and GeoSPARQL queries, the ontology's ability to represent both advertising information and the context in which ads should be recommended was demonstrated. It also successfully provided recommendations tailored to the user's current context (location, time, and type of need).

For future work, the plan is to develop a mobile context-aware advertising recommendation system that leverages the proposed ontology. This system will use the ontology to identify the types of concepts and semantic relationships present in the available advertising and contextual information, and based on this knowledge, deliver relevant recommendations that align with the user's current situation.

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