Using Networked Ontologies to support UX Evaluation in Immersive Context

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ABSTRACT

Over the past few years, new interactive systems such as immersive technologies have gradually permeated our daily lives and found adoption across various fields. Immersive technologies provide users with immersive experiences. Assessing and modeling the quality of such experiences has become a trending topic in HCI, and UX is a key quality attribute in this context. When it comes to immersive experiences, evaluating UX is particularly challenging because the user should not be interrupted to provide feedback. In this paper, we propose using networked ontologies to support evaluating immersive experiences. We have explored using ontologies from an ontology network addressing the HCI domain to develop a tool that supports UX experts evaluating such experiences based on data recorded in interaction logs. We used the ontology-based tool to evaluate the UX of an immersive application that supports collaborative music composition. The tool extracted data from the application interaction logs applied UX metrics, and provided consolidated data and information in graphs and tables. We conducted a study and collected feedback from the tool developer and three UX experts who used the tool. Results showed that using networked ontologies to develop a tool to support UX evaluation is feasible and valuable. In summary, the ontologies helped at the conceptual level by offering a basis to define the system's structural model and at the implementation level by assigning semantics to data to make inferences about UX. Based on the UX experts' perceptions, the tool was considered a promising system, beneficial, helpful, and easy to use.

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CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**; **HCI theory, concepts and models**; **Interactive systems and tools**; • **Information systems** → **Ontologies**.

KEYWORDS

User Experience, UX Evaluation, Immersive Experience, Ontology, Ontology Network

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1 INTRODUCTION

Digital and contemporary society has required increasingly better interactive systems. The success of an interactive system for human use depends not only on its ability to provide functionalities to meet the users' goals and needs, but also on the experience the system provokes in the users while interacting with it [21].

Human-Computer Interaction (HCI) is mainly interested in designing and evaluating interactive systems for human use and related phenomena [5]. HCI community values the quality of use [21] and develops and applies evaluation methods to assess it [10, 37]. Usability and user experience (UX) have been recognized as determinants of the interactive system quality and indicators of system success or failure [21]. In general, UX refers to the quality of the interaction between an interactive system and its user. Therefore, usability can be seen as a subset of UX [21].

Evaluating interactive systems requires capturing data referring to the system itself (e.g., its user interface) and its use (e.g., the user interaction when using the system). We can collect data in different ways, such as observation, inspection, and collection during system usage [5, 35]. Usually, when evaluating UX, it is common to observe users in a certain activity [36] or use questionnaires for users to self-report the experience. However, collecting data may not be trivial, particularly for systems involving many users and interactions. In these cases, collecting data automatically is helpful because it does not require user effort and contributes to obtaining the necessary data for evaluation. Besides collecting data, it is necessary to associate it with the qualities to be evaluated and analyze data to get conclusions that characterize the system and its use.

UX is subjective and associated with a broad range of fuzzy and dynamic concepts, including emotional, affective, experiential, hedonic, and aesthetic variables [25]. UX is also understood in terms of its dimensions: Enjoyment/Fun, Motivation, Frustration, Engagement, and others. [36]. Inferring the dimensions that make up UX through automatic data collection is challenging. However, some dimensions, such as engagement, can be analyzed from objective measures (e.g., considering the time and number of interactions a user provides when interacting with an interactive system [26]). Thus, we can define metrics to collect information regarding the interaction and analyze user engagement [34].

Interactive system evaluation also involves much knowledge. Besides knowing the system qualities to be considered, it is also necessary to understand the evaluation process and adequately deal with collected data. Ontologies can help in this matter. They have been recognized as an effective way to structure knowledge and assign semantics to data [16]. Thus, in this paper, we advocate using ontologies to aid the evaluation of interactive systems. More specifically, we propose to use ontologies from HCI-ON, an ontology network that addresses the HCI domain [13], to develop a tool that helps evaluate the UX provided by immersive technologies. Immersive technologies aim to engage [26] and create a sense of immersion for the user, to the point that the boundaries between the physical and virtual worlds are blurred [44]. They include several types of technologies, such as virtual reality (VR), augmented reality (AR), mixed reality (MR), and mobile apps [26, 44].

HCI-ON [13] contains a set of interconnected ontologies (i.e., networked ontologies) that provides a comprehensive and consistent conceptualization of the HCI domain, addressing subdomains such as HCI phenomena, user, interactive system, HCI design, among others. The ontology network structures knowledge and provides a comprehensive and consistent conceptualization. Thus, when one wants to use the conceptualization to address an HCI-related problem, it is possible to use the ontology network as a whole or only a fragment extracted according to the domain portion of interest.

The tool, called UXON (User eXperience evaluation based on Ontology Network), was developed to solve a problem reported by some HCI experts that needed to evaluate the UX of *Compomus*, a mobile entertainment application and immersive technology that can be used by many people to collaboratively compose music. Its goal is to create a sense of immersion for the user by transforming the audience's role from a mere spectator to an active element of the show [2, 26].

Compomus UX is measured by means of user engagement in the immersive interaction. Thus, it is necessary to collect data during the user interaction with the mobile application, use collected data to calculate UX metrics (e.g., engagement), and analyze them to get conclusions. Since interaction data regards many users and should be collected without interrupting the user experience, it is not feasible to collect and analyze data manually. Thus, an automated solution is needed.

The solution consists of using networked ontologies from HCI-ON as a basis for the tool that collects and stores data, performs reasoning, calculates UX metrics, and presents consolidated data about UX. UXON was used by three HCI experts, who considered it a promising system, very helpful, useful, and easy to use. Moreover, feedback provided by the UXON developer indicates that the use of networked ontologies was of great support to developing the tool. They helped mainly in defining its structural model, better understanding and covering the HCI domain addressed by it, and assigning semantics to data, enabling inferences to evaluate UX.

This paper describes our experience using an extract of HCI-ON to develop UXON and support UX evaluation. We also briefly present the results (mainly qualitative) of a study performed to capture UXON users and development feedback about the tool and the use of networked ontologies to develop it. This paper contributes to researchers by proposing an ontology to address HCI evaluation aspects, exploring the use of networked ontologies to build a solution related to HCI evaluation, and shining a light on the need for addressing semantics in the HCI domain. On the other hand, practitioners can benefit from the developed tool and can learn how to develop similar ones to evaluate other interactive systems.

The paper is organized as follows. Section 2 provides the background for the paper. Section 3 introduces the problem. Section 4 presents the HCI-ON fragment used to develop UXON. Section 5 presents UXON. Section 6 concerns UXON users and developer perceptions. Section 7 discusses related work. Lastly, Section 8 concludes the paper.

2 BACKGROUND

2.1 HCI Evaluation and Immersive Experience

UX and usability are two key quality attributes when evaluating interactive systems. While usability is a task-oriented attribute that measures the extent to which an interactive system, product, or service allows users to achieve their goals efficiently and effectively [24], UX is more holistic [5, 21, 22, 30].

UX refers to the user's overall experience when interacting with an interactive system. It encompasses all aspects of the user's interaction, including usability, accessibility, and aesthetics, offering a much more holistic and dynamic take on interaction with interactive systems [36]. The system must fulfill user expectations and create a positive UX to succeed [5, 21, 27]. Therefore, UX has attracted increasing interest in recent years [36], extending the perspective on usability to less pragmatic, more hedonic, and non-task-oriented considerations about interactive systems [22, 23].

In UX research, evaluation is one of the core pillars [36]. Evaluating UX is challenging because users may have trouble expressing their experiences if directly asked to [38]. The challenge becomes even more complicated when dealing with experiences in which the user cannot be interrupted to provide feedback, such as those experiences provided by immersive technologies. In general, immersive technology is a technology that blurs the boundary between the physical and virtual worlds and enables users to experience new sensations, such as immersion [44]. To get the experience to the utmost, the users should not be interrupted during it [26].

There are methods in which UX evaluation is based on user observation [35], which allows the recording of interaction data and measurement of collected data [5] to reach conclusions about these characteristics of quality of use. Observation ensures that the user is not interrupted during their interaction experience [37]. Observation methods can be classified as direct (user-based evaluation), when data is directly recorded by the evaluator observing the user; and indirect (data collected during usage), when data is recorded by the system itself during its use (interaction logging) – i.e., it is indirectly recorded and does not require the presence of the evaluator during data collection [5, 35, 37]. In both, data from interactions and situations that may occur while the user interacts with the system are recorded and analyzed (or measured) and allows identifying problems during the user experience [5, 37].

Direct observation is best when a small group of users is involved. On the other hand, when it is necessary to observe the interaction of many users, indirect observation becomes more appropriate. Both can involve metrics and measurements of collected data and can be complemented with interviews and questionnaires applied to users after using the system [35, 37].

A metric[1] allows characterizing a particular entity by quantifying its properties [7]. Thus, metrics related to UX quantitatively describe some perspectives of this experience [1]. They show, based on quantitative values, some aspects of the interaction between the user and the system, such as effectiveness (ability to perform a task) and efficiency (the amount of effort used to complete the task). A striking feature of metrics related to UX is that they measure something related to human beings and their interaction [1]. In our work, metrics are applied to data from interaction logs to quantify UX in the immersive context (details in Section 3).

2.2 Ontology

An ontology is a formal and explicit specification of a shared conceptualization [42]. The conceptualization is an abstract and simplified view of the world that is intended to be represented for some reason. Every system is committed, either explicitly or implicitly, with one conceptualization [41].

An important distinction differentiates ontologies as conceptual models, called *reference ontologie*s, from ontologies as computational artifacts, called *operational ontologies* [17, 19]. A reference ontology is constructed with the goal of making the best possible description of the domain in reality, regardless of its computational properties. Operational ontologies, in turn, are designed with the focus on guaranteeing desirable computational properties and, thus, are machine-readable ontologies.

Both reference and operational ontologies have been used to aid software development. The former is suitable for supporting the description of the application domain itself and is applied in development time, a.k.a, *ontology-driven development* (ODD) [20]. The latter is appropriate for use as primary artifacts in run-time and plays a major role in application logic, a.k.a, *ontology-based architecture* (OBA) [20].

For large and complex domains (such as HCI), ontologies should be organized in an *ontology network* (ON), which consists of a set of ontologies connected through relationships in such a way as to provide a comprehensive and consistent conceptualization. In an ON, *networked ontologies* are modular and related together through a variety of relationships (e.g., modularization, alignment, dependency), sharing concepts and relations with other ontologies and, thus, forming a network of interlinked semantic resources [13, 43]. In the work described in this paper, we used networked ontologies of an HCI ontology network. When developing the proposed tool, reference ontologies supported ODD and operational ontologies supported OBA (details in Section 5).

[1]In this work, the terms *metric* and *measure* are adopted as synonymous.

3 UNDERSTANDING THE PROBLEM

Compomus [2, 26] is an immersive spatial music composition application that collects interaction data (interaction logging) from various users during the collective production of music. The musical composition event is carried out in sessions configured in a time interval and in groups of people who occupy the same room with four speakers. Each person in the session uses *Compomus* on their cell phone to choose from 50 types of sound (Figure 1). When a person chooses a sound, it is played on the speaker closest to that person, simultaneously emitting the sounds chosen by the other participants who are close. The idea is that the sound of each person and their respective movements create a musical composition, providing the sense of presence, depth perception, flow, and engagement. The speakers are geographically positioned, forming the musical environment (a rectangle), and people move within this environment, selecting/playing sounds on the speakers through interaction with *Compomus* (Figure 1). For each person and each movement or sound choice in this environment, *Compomus* records in an interaction log file (Figure 2) the following data: *person*, *x*, *y*, *z*, *time*, *hour* and *sound* (first line of Figure 2).

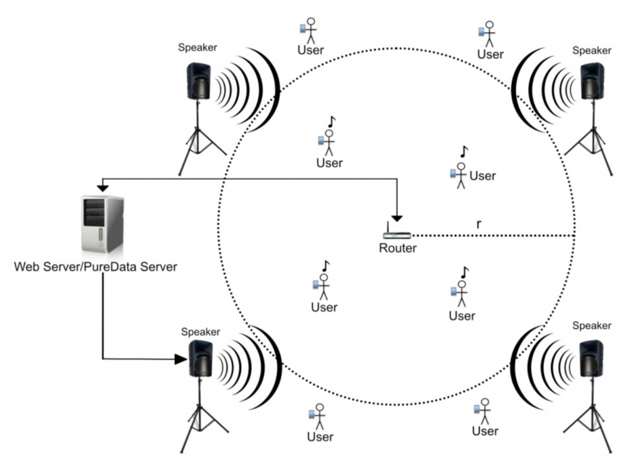
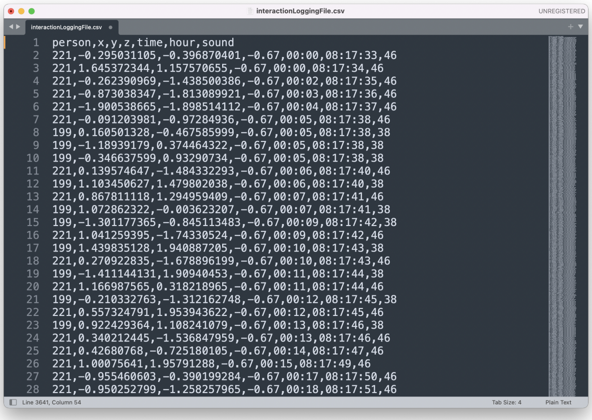


Figure 1: *Compomus* environment. Adaptated from [2].

Person refers to the participant ID. Data from *x*, *y* and z[2] together refer to the *Person's geolocation* in the music composition environment. *Time* refers to the duration of the session until the data record.

[2]As the music composition environment is two-dimensional, and *z* refers to the third dimension in a dimension structure, despite being recorded in the log, it is not used as it does not reflect an interaction of geolocation change in the use of *Compomus*.




```
person,x,y,z,time,hour,sound
221,-0.295031105,-0.396870401,-0.67,00:00,08:17:33,46
221,1.645372344,1.157570655,-0.67,00:00,08:17:34,46
221,-0.262390969,-1.438500386,-0.67,00:02,08:17:35,46
221,-0.873038347,-1.813089921,-0.67,00:03,08:17:36,46
221,-1.900538665,-1.898514112,-0.67,00:04,08:17:37,46
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199,-1.18939179,0.374464322,-0.67,00:05,08:17:38,38
199,-0.346637599,0.93290734,-0.67,00:05,08:17:38,38
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199,-1.301177365,-0.845113483,-0.67,00:09,08:17:42,38
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221,-0.950252799,-1.258257965,-0.67,00:18,08:17:51,46
```

Figure 2: *Compomus* interaction log file.

Hour refers to the time the interaction took place. *Sound* refers to the sound chosen by the *Person*.

Aiming to understand the interaction during the music session experience and analyze the user engagement when using *Compomus*, some HCI experts used data recorded in the logs to calculate the following metrics [26]:

- *User interactivity*: related to any activity between the user and the computer. In this sense, the authors understand interactivity as the interaction time of each participant since the time covers the total time of the user participating actively in an immersive experience, counting the individual user interaction time. The variables of this metric are: the overall experience time (T_{sg}), obtained through the start (T_i) and end time (T_f) of the experience. The user time (T_{ui}), obtained through the logoff time (T_{off}) and the user login time (T_{in}). Finally, the interaction time (T_{sec}) is calculated using the following formulas:

$$T_{sg} = (T_f - T_i)$$

$$T_{ui} = (T_{off} - T_{in})$$

$$T_{sec} = \left(\frac{Tui}{Tsg}\right) * 100$$

- *User interactions*: interaction can be understood as an attribute of interactivity, the user-specific actions in human-computer interaction. In this sense, this metric is responsible for evaluating the quality of the interactivity time in terms of each participant's engagement (active participation). In the case of *Compomus*, the sound change (*sound*) and the geolocation change (*x*, *y*) are considered. This metric is calculated using the following formula:

$$MC = \sum_{j}^{n} v$$

The above formula is generic for the user interaction metric. The sum indicates the number of interactions, v is the variable that represents the recorded interaction, and the variation from j to n indicates the number of records.

- *Percentage of interactions*: responsible to get the percent of users interaction, using the participant with the highest number of interactions as a *benchmark* (100%) and analyzing the other participants in relation to this value. The variables of this metric are: the percentage of interactions of user u (P_u), the value of the metric of user interaction u and the value of the metric of the interaction of the most active user b (*benchmark*) (P_b). This metric is calculated using the following formula:

$$P_u = \frac{MC_u}{MC_b}$$

To extract data from the log file and use them to calculate the metrics, the HCI experts had to write and execute codes. This required much effort, was error-prone, and provided little support for data analysis. Aiming to build a better solution to support HCI experts to evaluate UX, and considering the successful application of ontologies to solve software development problems (e.g., [8, 29, 40]) and the promising use of networked ontologies [39], we decided to use ontologies from HCI-ON to develop UXON to support UX evaluation.

4 THE CONCEPTUALIZATION BEHIND UXON

HCI-ON is an ontology network that contains several networked ontologies addressing HCI subdomains. The network is organized in layers according to the ontologies' generality level, favoring knowledge growth, reuse, and integration. At the top, HCI-ON has the Unified Foundational Ontology (UFO) [18], which models basic and general concepts and relations that make up the world (such as objects, events, participation, and parthood) and provides the well-defined and common ground to all HCI-ON ontologies. At the center, core ontologies refine general concepts by adding concepts and relations of a specific area that still spans across various subdomains. Lastly, at the bottom, domain ontologies describe knowledge specific to a particular domain.

In Figure 3, we present the HCI-ON extract relevant to this paper (for simplification reasons, UFO concepts are not shown). It contains concepts from three networked ontologies, namely: the *Core Ontology on Measurement* (COM) [6], which addresses core concepts related to measurement and includes concepts such as Measure, Measurement, and Measured Value; the *Human-Computer Interaction Ontology* (HCIO) [14], which regards the core conceptualization about the interaction between user and interactive computer system, addressing concepts such as User, User Participation, Human-Computer Interaction; and the *Human-Computer Interaction Evaluation Ontology* (HCIEO), a domain ontology that addresses several aspects and different kinds of HCI evaluation, involving concepts such as HCI Evaluator, HCI Evaluation Report, and HCI Evaluator, among others. In the figure, a dashed line separates concepts from different ontologies, while a double-dashed line separates ontologies at different layers. After the figure, we provide a brief description of the concepts. The current version of HCI-ON, including the complete specification of the aforementioned ontologies and also others, is available at https://dev.nemo.inf.ufes.br/hcion/. The use of UFO to ground the networked ontologies is out of the scope of this paper and can be found at [11].

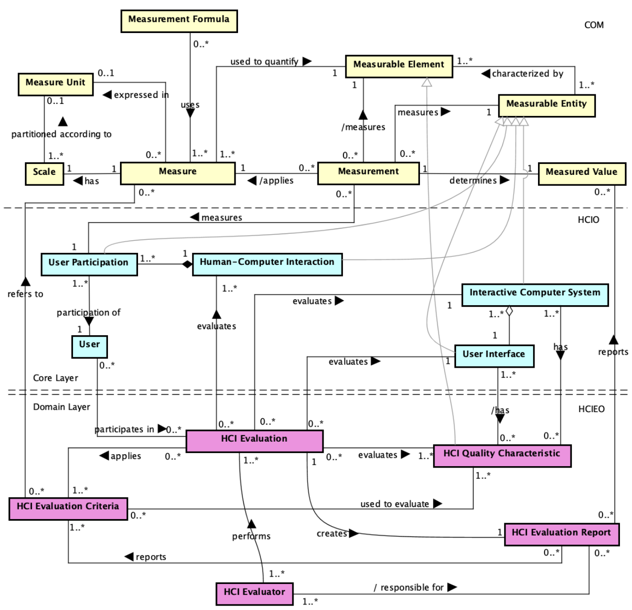

Figure 3: HCI-ON extract.

A *Human-Computer Interaction* represents the communication between a *User* and an *Interactive Computer System* through the system's *User Interface*. *Human-Computer Interaction* is a complex event that involves the *User Participation* (i.e., the user actions during the interaction) and the system participation (not shown in Figure 3).

An *HCI Evaluation* represents an event caused by the intention of an *HCI Evaluator* and consists in determining the extent to which the *HCI Quality Characteristics* (e.g., UX, usability) of an *Interactive Computer System* meet the *HCI Evaluation Criteria* applied in the evaluation. *HCI Evaluation Criteria* are conditions or capacities the system is expected to satisfy. *HCI Evaluation Report* is an artifact (e.g., a document) that records the evaluation results and other relevant information about the evaluation (e.g., the considered HCI evaluation criteria).

In some *HCI Evaluations* is necessary to perform measurements to quantitatively evaluate whether the *HCI Quality Characteristics* of an *Interactive Computer System* meet the *HCI Evaluation Criteria*. For that, in order to evaluate the system, it is possible to quantify characteristics of the system itself, its interface or the interaction. In the measurement context, *Measurable Entity* is an entity (e.g., a person, a system) that can be measured, i.e., characterized by quantifying its properties. Thus, *Interactive Computer System*, *User Interface*, *Human-Computer Interaction* and *User Participation* are measurable entities, while *HCI Quality Characteristics* are properties that can be measured to characterize them (i.e., *Measurable Elements*).

A *Measure* (e.g., time spent to log in the system) can be expressed in a *Measure Unit* (e.g., second) and has a *Scale* partitioned according to the *Measure Unit* and composed of the values that can be associated with the *Measure*. *Measurement* consists in collecting *Measured Values* to a *Measure* (e.g., the measurement of the time to log in the system, resulting in the value 40 seconds). *Measurement Formula* represents the formula adopted to associate a *Measured Value* to a *Measure* in a *Measurement* (e.g., the formulas presented in 3 are used to calculate values to the referred measures). In an *HCI Evaluation*, *Measurements* are performed to establish *Measured Values* to quantify *HCI Quality Characteristics*.

5 UXON: USER EXPERIENCE EVALUATION BASED ON ONTOLOGY NETWORK

An overview of UXON is shown in Figure 4. In a nutshell, *Compomus* captures data regarding the user interaction and records it in the interaction log file. The UX evaluator uploads the interaction log file. Then, an ETL (Extract Transform and Load) process is performed using the HCI-ON extract to assign semantics to data. Data is stored in a triplestore to calculate metrics and provide other information, which is searched using SPARQL[3]. The results can be visualized in different graphs and tables. The UX evaluator visualizes the results and analyzes them. Data and analysis results are recorded in an evaluation report. The ETL process, data persistence in the triplestore, and SPARQL queries all use the operational version of the HCI-ON extract (ontoUXON) used in the solution.

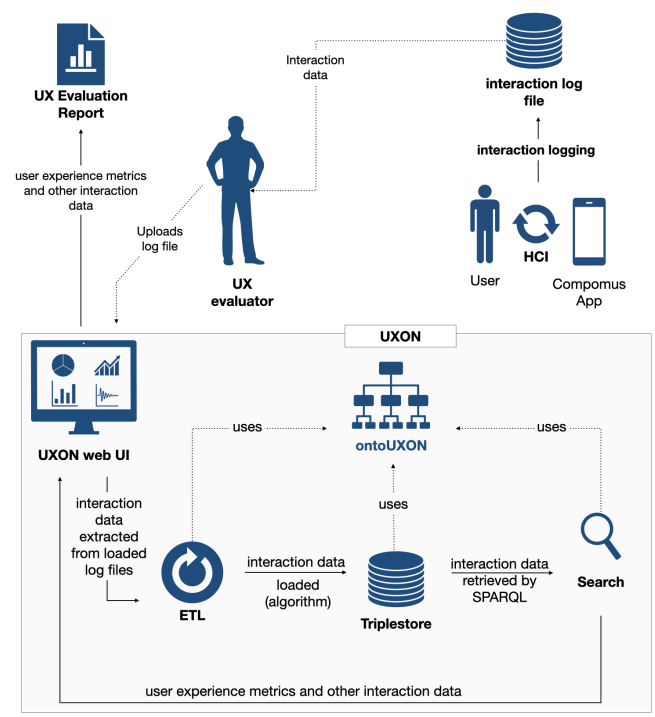

Figure 4: UXON overview.

[3]SPARQL is a query language for RDF. It can be used to express queries across diverse data sources, whether the data is stored natively as RDF or viewed as RDF via middleware.

The development of UXON was based on the HCI-ON extract presented in Section 4 and followed the Ontology-Driven Development (ODD) and Ontology-Based Architectures (OBA) approaches [20]. The HCI-ON extract played a fundamental role. At development time (ODD), it contributed to understanding the application domain (i.e., HCI evaluation) and defining UXON's business and application logic (translated into business rules and algorithms) and defining UXON conceptual structural model. The HCI-ON fragment (reference conceptual model) was transcribed into OWL, resulting in ontoUXON (operational artifact), which at run-time (OBA) enabled the ETL process. As ontoUXON is an RDF graph/knowledge graph, it was used as the dataset (data model) in the UXON triplestore configuration. Consequently, ontoUXON was used to express queries (SPARQL) across it. To put it in another way, all data and also measured values are instantiated in ontoUXON and later stored in the triplestore, which is searched by SPARQL queries. In the next sections, we present the UXON conceptual model, ontoUXON and describe some features.

5.1 UXON's Conceptual Model

After selecting the HCI-ON fragment necessary to support development, we made some adjustments in the conceptual model to turn it into an information model, which is more suitable for implementation[4]. In summary: (i) we did not represent the Measurable Entity concept because, considering the HCI expert needs and used metrics, the only entity measured in UXON is User Participation (with that, the *measures* relation between Measurable Entity and Measurement is represented between Measurement and User Participation); (ii) the relationship *is quantified by* between User Participation and Measure was created (even though this information can be obtained from the relationships between User Participation, Measurement, and Measure); (iii) Scale Value, Measure Unit, Measurement Formula, and Measurable Element[5] concepts were represented as attributes of measure; (iv) the Measured Value concept was represented as a Measurement attribute; (v) attributes were created to store data, such as the evaluator's name and its comments resulting from data analysis. We also adjusted the model to make it able to store data specific to the problem domain. For that, we defined new attributes to User Participation and Human-Computer Interaction to store data about the user interaction when using *Compomus* (e.g., user participation geolocation, sound, and interaction time). Figure 5 shows the resulting conceptual model.

5.2 ontoUXON Operational Ontology

From UXON conceptual model, we created ontoUXON, by transcribing the model to OWL using the Protegé[6]. Figure 6 present fragments of ontoUXON code. Semantic Web technologies (OWL, RDF, etc.) allow representing knowledge in RDF triple [Subject → Predicate (or "Property") → Object] and RDF graph. Figure 7 illustrates these fragments in the form of an RDF/ knowledge graph. RDF graphs are used as databases in the triplestore format (i.e., subject-predicate-object). ontoUXON is available at https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#.

[4]An *information model* concerns what kind of information may be stored and exchanged considering demands of specific agents (the "recorded world"), while an ontology model concerns metaphysical aspects of a domain (i.e., it concerns what is considered to exist in the "real world"). Thus, by turning the ontological model into an information model, the resulting model preserves the conceptualization in a structure more suitable for computing demands [9].

[5]For simplification reasons, although the same measurable element can be quantified by more than one measure, in UXON, a measurable element (e.g., interaction, interactivity) is treated in only one measure.

[6]Protégé is a free and open source ontology editor. The version used was 5.5.0.

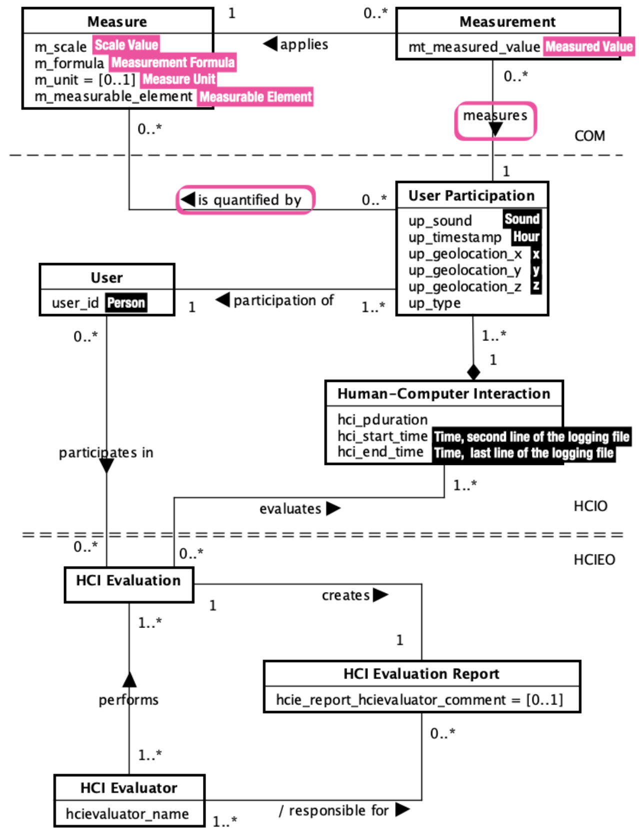

Figure 5: UXON conceptual model.

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<!--  Representation of Concepts (Measurement, User and UserParticipation), Object and
    Data Properties (is_measured_by; mt_measured_value)  -->

<!--  Concepts  -->
<!--  https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#Measurement  -->
<owl:Class rdf:about="https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#Measurement"/>
<!--  https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#User  -->
<owl:Class rdf:about="https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#User"/>
<!--  https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#UserParticipation  -->
<owl:Class rdf:about="https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#UserParticipation"/>

<!--  Object Property  -->
<!--  https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#is_measured_by  -->
<owl:ObjectProperty rdf:about="https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#
    is_measured_by">
<owl:inverseOf rdf:resource="https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#measures"/>
<rdfs:domain rdf:resource="https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#
    UserParticipation"/>
<rdfs:range rdf:resource="https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#Measurement"/>
</owl:ObjectProperty>

<!--  Data Property  -->
<!--  https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#mt_measured_value  -->
<owl:DatatypeProperty rdf:about="https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#
    mt_measured_value">
<rdf:type rdf:resource="http://www.w3.org/2002/07/owl#FunctionalProperty"/>
<rdfs:domain rdf:resource="https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#Measurement"/>
<rdfs:range rdf:resource="http://www.w3.org/2001/XMLSchema#decimal"/>
</owl:DatatypeProperty>
```

Figure 6: Fragment of ontoUXON.

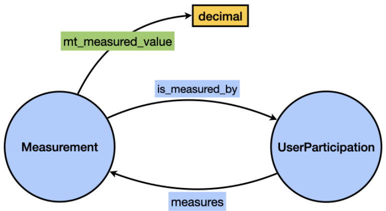

Figure 7: RDF graph.

5.3 UXON's Features

In this section, we present some of the UXON features by showing screenshots and brief descriptions. The source code is available at https://github.com/cfmanso/UXON-final. The tool is available at https://dev.nemo.inf.ufes.br/uxon/. We provide a video showing how UXON works at https://bit.ly/UXON_overview. UXON development adopted technologies that enable web solutions, such as the Flask web framework, the Python programming language, the HTML markup language, and CSS styling. Semantic Web[7] technologies were also used to create and handle the operational ontology, namely: OWL, RDF, and SPARQL languages, and the Owlready2 and SQLite3 libraries.

When using the UXON, the UX evaluator must upload on the tool main page the log file(s) referring to the *Compomus* session(s) to be considered in the evaluation. In the background, the tool extracts data from the file(s) and instantiates it in ontoUXON according to the assigned semantics. Then, the tool uses extracted data to calculate the metrics and instantiates the values in ontoUXON. Instantiated data is, thus, persisted in the triplestore. Once data is stored, the UX evaluator can visualize the results in graphs and tables. For example, the UX evaluator can access in a table the values related to the metrics for each user or consider all users that participated in the composition session. Next, we show some screenshots of graphs provided by the tool.

Figure 8 illustrates bar charts showing data regarding *interactivity*, *interaction*, and *percentage of interactions* considering all users that participated in the session. Additionally, Figure 9 shows the "Top 5" graphs provided by the tool, which indicate the five most emitted sounds and the five most active users in the session. These graphs help the UX evaluator verify if the users' interaction was according to the expected, if they interacted similarly, or if some users presented different behaviors. The UX evaluator can use other evaluation methods (e.g., interview) to complement the quantitative evaluation and understand the reasons for the user engagement.

UXON also helps UX evaluators go beyond the metrics and have a dynamic view of the users' interaction. For that, it provides geolocation maps with information about the movements made by the users during the session. In the graphs, the x and y coordinates indicate the user location in the session environment, and different colors indicate the different sounds the user played at each location. The maps can be viewed from a static (Figure 10) or dynamic (Figure 11) perspective (i.e., the points move in the graph according to the user movements during the session).

[7]The Semantic Web is the web that can be processed by computers and that, at the same time, is readable by humans. It adopts W3C technology standards [45].

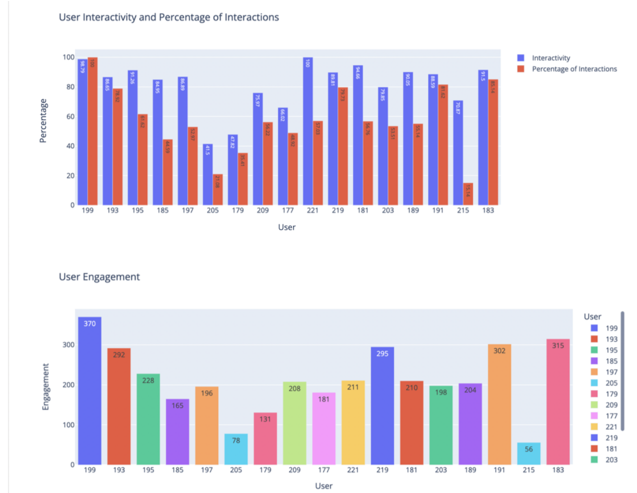

Figure 8: Bar charts with UX metrics related to all users.

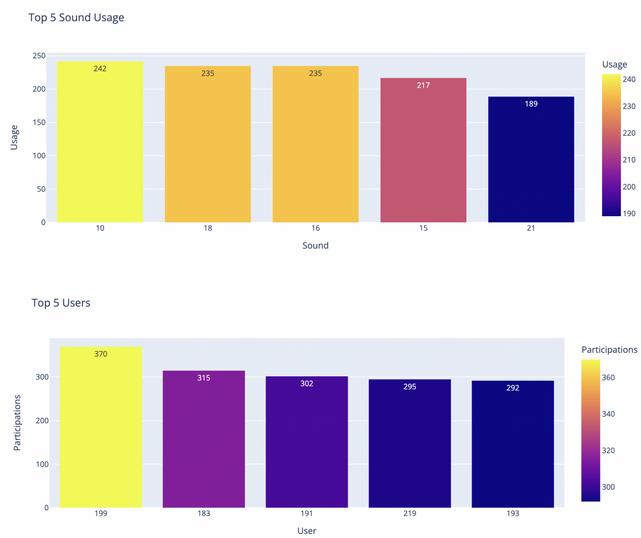

Figure 9: Top 5 sounds and users.

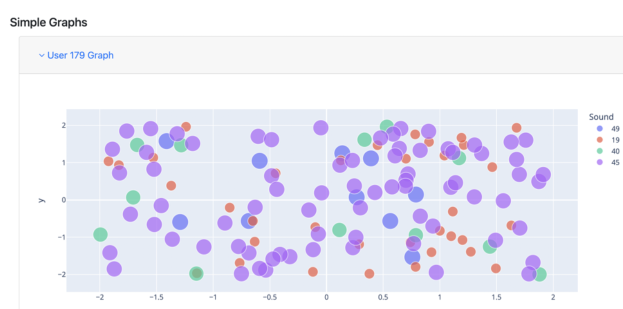

Figure 10: User interaction (static perspective).

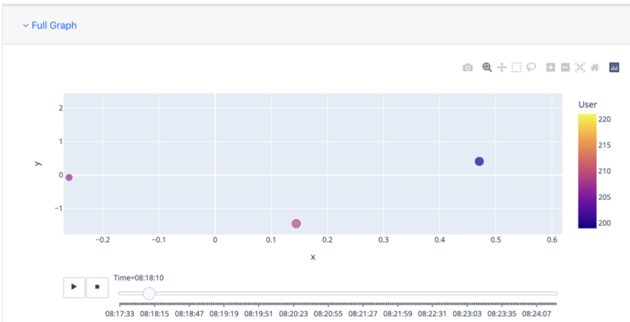

Figure 11: Users interaction (snapshot of the dynamic perspective) .

In addition to several tables and graphs to visualize metrics values and complementary information, UXON also provides features that allow the evaluator to perform searches in data as desired. The UX evaluator can use predefined queries offered by the tool to analyze the users participation in the session (e.g., by using some filters, the evaluator can search for user interactions that involved sound change or ask how many times the users chose a sound). The evaluator can also define new queries to search data in different ways, considering several parameters (e.g., user, emitted sound, type of interaction, interaction range). Figure 12 illustrates a piece of the custom queries page.

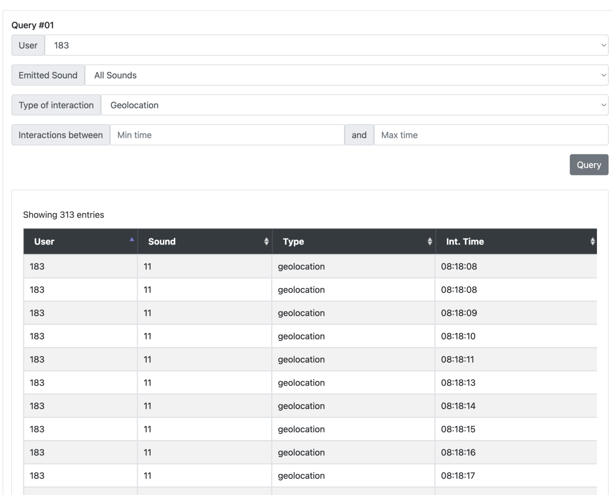

Figure 12: Custom Queries page.

Finally, after analyzing data about the user interactions, the UX evaluator records her/his analysis and conclusion about the *Compomus* UX in an Evaluation Report and can download a PDF file containing all graphs and tables considered in the evaluation plus the evaluator comments. Figure 13 depicts the screen in which the evaluator inputs their comments.

The effort and time spent manually on getting and structuring data from many users through log files are very high. UXON contributes to decreasing the time and effort spent on handling data, enabling the UX evaluator to focus on data analysis and interpretation. Based on the information obtained from log data and the calculated metrics, it is possible to analyze and reflect on the UX provided by *Compomus*. In addition, the graphs and tables generated by the tool make it easier to identify users who participated the most and how they participated. Such information about user interaction helps perceive interaction patterns that can describe how users interact, adding more richness to UX analysis.

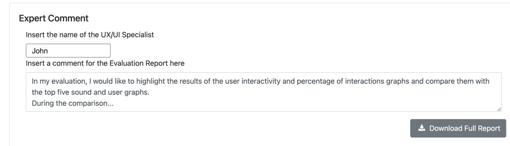

Figure 13: Evaluation Report screen.

6 PERCEPTIONS FROM THE UXON USERS AND DEVELOPER

The use of an HCI-ON extract to develop UXON demonstrated that using networked ontologies to develop a system for solving HCI evaluation problems is feasible. We performed a study to verify if the produced solution is suitable for solving the aimed HCI problem. We applied a questionnaire to three users of UXON to get their perception of the tool. In addition, to obtain feedback about using HCI-ON to develop the tool, we performed an interview with its developer. These studies allowed us to evaluate our proposal from user and developer perspectives. The studies were approved by The Ethics Committee of Federal University of Amazonas (UFAM), with registration number (CAAE): 51490121.0.0000.5020.

Our goal in investigating the *User* perspective was to evaluate the tool's usefulness and feasibility. The procedure adopted in the study consisted of briefly presenting the tool to three UX evaluators and making it available for around 30 days. After that, we invited them to answer a questionnaire. Thus, we analyzed their answers according to the study goal. The questionnaire used in the study is available at https://bit.ly/3qbQwHL.

The participants were the three UX evaluators [8] who had previously evaluated *Compomus* UX without a specific supporting system (they extracted data from the interaction logs by implementing a program to do that, imputed data in electronic spreadsheets, and calculated the metrics). Thus, these UX evaluators knew how to evaluate *Compomus* UX and would be able to compare the tool with the previous solution they used. Participants P1 and P2 are Ph.D. students who declared to have, respectively, high and medium theoretical knowledge of and practical experience in UX Evaluation. P3 is a senior researcher who had a Ph.D. degree and declared to have high theoretical knowledge of and practical experience in UX Evaluation.

Regarding *usefulness*, we observed that, in general, all participants had the same or a very close perception. They agreed that UXON is very helpful and useful, automates UX evaluation tasks, improves the quality of data presentation and data analysis, and

[8]In evaluations involving specialists, a previous study recommended using groups of 3-5 evaluators [5, 33].

strongly decreases time and effort spent to evaluate *Compomus* UX. For example, according to participant P1, UXON plays an important role in supporting the analysis of UX data and automates a process that could take longer. He also stressed that data presentation is excellent, avoids more extensive analysis work, and allows analyzing individual data, which previously required a lot of effort. P2 pointed out that the tool is capable of plotting graphs from very large log files, which is challenging even for those who have some affinity with data processing systems. Moreover, he stated that UXON reduced the time and effort to obtain the desired information. P3, in turn, emphasized that UXON offers useful metrics and graphs to analyze how *Compomus* users interacted and engaged, allows visualizing information in a simple way and provides graphs and statistics easy to analyze. He also highlighted that it was much easier to perform data analysis using UXON and that previously, the analysis was performed manually, through scripts, and the cost of developing and testing these scripts is very high. As a drawback, P1 said that due to the interactive graphics, there is a delay in data processing and that a more visible loading message would be nice for the evaluator to know that the data is being processed.

The participants also agreed that using the tool was neutral to help identify improvements in the *Compomus* when compared to the previous solution. We believe that this is due to the metrics currently available, which may not be enough to provide information to suggest improvements in *Compomus*.

Regarding *feasibility*, the participants agreed that UXON is easy to use. Moreover, they would use the tool again, and most would recommend it to others. P1 said that UXON exponentially facilitated his HCI evaluator job. P3, in turn, emphasized that they intend to use the tool whenever he needs to evaluate data from music composition sessions and *Compomus* UX. One participant (P3) said that he would not recommend the tool only because it is specific to *Compomus*, and other people may not be interested in that. Although this does not precisely represent a limitation, as the tool was developed to specifically support *Compomus*, it points to the need to evolve UXON to handle data from other applications.

As for the advantages of using UXON, participants reinforced automation, data representation, simplicity, ease of use, support to data analysis, and decrease of time/effort. Concerning disadvantages, they highlighted data processing time, evaluation report graphic quality, and the fact that the tool only works for *Compomus*. In summary, based on the participants' perceptions, UXON was considered a promising system, helpful, useful, and easy to use. But, some improvements are still needed.

The goal of the interview performed to capture the *developer* perspective was to investigate, from the developer's point of view, whether the use of networked ontologies from HCI-ON helps the development of a system to support solving HCI-related problems. Aligned to this goal, we defined two main questions: (Q1) If and how did the use of networked ontologies from HCI-ON help in the development of a system to support the solution of HCI evaluation-related problems (specifically UX evaluation)?; and (Q2) What were the benefits and difficulties of using networked ontologies in that context? The participant of the study was the UXON developer who has an undergraduate degree in Computer Science and declared to have high theoretical and practical knowledge of systems development and medium knowledge of ontologies and ontology-based system development. The procedure adopted in the study consisted of a face-to-face approach and a semi-structured interview. The interviewer decomposed Q1 and Q2 into other questions that served as a guide to the interview and a checklist of the topics to be covered. The questions used to guide the interview are available at https://bit.ly/3qbQwHL.

Regarding Q1, the results indicated that using networked ontologies was helpful. According to the tool developer, the HCI-ON extract provided significant support to the system analysis phase, particularly to the modeling activity. Furthermore, the HCI-ON extract helped to gain a better understanding and coverage of the HCI domain addressed in the application, and its semantics helped in the tool development. As a drawback, the developer stressed that the ontologies did not support the design phase, and she had some difficulties in the implementation phase. However, they were mainly due to the used technologies (e.g., Flask, Python) and not because of the ontology.

Concerning Q2, the developer feedback indicated that the main benefits of using networked ontologies are the ease of understanding the domain and the shortening of the learning curve compared to non-ontology-based software development. Furthermore, the developer suggested that while the ODD approach may be suitable for novices in ontology-oriented software development or with little experience in ontologies, OBA applications may require more expertise. As reported by the developer, the most significant difficulty she had was not with using the networked ontologies but with the used technologies. She reported that this difficulty may be due to the lack of knowledge and time to study. Using operational ontology in software coding can be challenging, especially for non-experts (the developer's case).

The overall results of the interview indicated that the use of networked ontologies helped in the tool development. The more outstanding contribution perceived by the developer was in development time (ODD approach). Due to the developer's difficulties with some technologies, we could not properly evaluate the contribution of the networked ontologies in run-time because the difficulties in using the technologies may have prevented her from perceiving the actual impact of using networked ontologies at run-time.

7 RELATED WORK

We consider related to our, works addressing ontologies concerning HCI evaluation or using them to support the development of solutions to aid HCI evaluation. We carried out a systematic literature review that investigated ontologies in the HCI domain [12] and we did not find any work using ontologies to support UX evaluation. By analyzing the selected papers, the only ones that cover HCI evaluation to some degree are the ones by Negru and Buraga [31, 32], Elyusufi et al. [15], and Mezhoudi and Vanderdonckt [28], which propose ontologies including concepts related to HCI evaluation methods. The proposal by Negru and Buraga [31, 32] includes Usability Test concept as a way to evaluate HCI, while the ones by Elyusufi et al. [15] and Mezhoudi and Vanderdonckt [28] address some concepts related to questionnaire. However, these works are not devoted to HCI evaluation and, in fact, contain only a few concepts related to that. Some works proposing HCI ontologies concern

HCI evaluation metrics: [3] addresses metrics in the context of pervasive experience and [4] structures some metrics related to Web user interface. Different from *OntNet*, which provides a comprehensive, consistent, and solution-independent conceptualization of HCI, these works focus on a single ontology developed for a specific application, hampering knowledge reuse to solve other problems. Moreover, the *OntNet* portion that covers HCI related to HCI evaluation addresses general evaluation aspects, regardless of the specific method to be applied. Therefore, it can be used to support different solutions, adopting different evaluation methods. Moreover, *OntNet* provides a conceptual framework that allows using any metric to support HCI evaluation, while [3] and [4] consider only some specific metrics for particular HCI subdomains.

From the cited works, only two use the proposed ontology in systems development ([15] and [4]) and only one of them uses it in the HCI evaluation context. In [4], the ontology was used as the basis for a meta-tool developed for assessing Web user interfaces using metrics from different providers. The paper does not provide enough information for us to analyze if the ontology is used in ODD or OBA approaches.

In this work, different from the ones aforementioned, we propose to use networked ontologies to aid in developing a system to support UX evaluation. By using an ontology network, we use a comprehensive and well-founded conceptualization and it is possible to extend the solution or developed new ones by considering other extracts of the network. Furthermore, we explored the use of ontologies at both, conceptual and operational levels, by adopting reference and operational ontologies at development and run-time, respectively.

8 FINAL CONSIDERATIONS AND FUTURE WORK

UX is a key quality attribute of interactive systems, with subjective characteristics such as feelings and emotions of the users [5, 21, 38]. Evaluating UX is not trivial, particularly in the context of immersive technologies, which provide users with immersive experiences that should not be interrupted to ask users for feedback. Moreover, when the experience involves many users, it may be difficult to manually collect data from all of them.

In view of the above, in this paper, we described our experience of using networked ontologies to provide a conceptualization of HCI evaluation and support the development of a tool to aid in UX evaluation in an immersive context. Ontologies have been recognized as essential tools for solving interoperability and knowledge-related problems [16]. Although they have been used in several domains, their use in HCI in general, and in HCI evaluation in particular, should be further explored [12]. With this work, we give a step in this direction and shine a light on opportunities to use networked ontologies to address HCI problems.

To aid HCI experts in UX evaluation, we developed UXON, which supports UX experts in evaluating immersive experiences based on data recorded in interaction logs. The tool automatically extracts data from interaction logs, uses them to calculate metrics, and presents the results in different formats. For developing the tool, we used an extract of HCI-ON. The networked ontologies helped at the conceptual level by offering a basis to define the conceptual structural model of the tool and at the implementation level by assigning semantics to data to make inferences about UX.

We conducted a study and collected feedback from the UXON developer and three UX experts who used it. Our results showed that using networked ontologies to develop a tool to support UX evaluation is feasible and valuable. The use of HCI-ON extract facilitated UXON development by providing the domain conceptualization, which was used in the tool conception and conceptual modeling. Moreover, at run-time, it enabled the ETL process and was turned into the tool triplestore, which can be searched by SPARQL queries. As a benefit, the use of HCI-ON extract helped decrease the time to understand the problem domain and create the tool conceptual model and database. As a drawback, implementing operational ontologies may require expertise in the involved technologies. Based on the UX experts' perceptions, the tool was considered a promising system, beneficial, helpful, and easy to use.

This work has some limitations that must be considered together with the results. We can highlight the fact that the HCI-ON extract used in the study was developed by some of the paper authors. Thus, they have knowledge of the ontologies, which helped clarify doubts the developer had about them when developing the tool. Another important limitation regards the tool evaluation. Only three UX experts used and evaluated UXON. These UX experts were selected because they had knowledge of the previously adopted solution to evaluate *Compomus*. On one hand, this is positive because they were able to compare the solutions and identify the improvements provided by UXON. On the other hand, previous knowledge may have influenced the results (i.e., if the tool is used by UX experts not familiar with the previous solution, the results may be different). The evaluation of using networked ontologies from the developer's point of view also has limitations. We got feedback from only one developer, who was not familiar with the technologies used to implement and use operational ontologies. Moreover, she knows the authors of the HCI-ON extract used to develop the tool and could ask them for clarifications during the development. Thus, developers with a different profile may have different perceptions from hers. Due to the limitations, the results obtained from the studies should be considered initial indications and do not provide a complete picture of the proposal's effectiveness. For this reason, the obtained results are preliminary evidence and cannot be generalized.

Considering these limitations, we intend to perform other studies using networked ontologies to support UX evaluation in other contexts (e.g., comparing evaluate UX by using other techniques and UXON). To do so, we intend to increase the set of UX metrics addressed in UXON. These studies will give us other evidence to compare to the findings we got so far. We also plan to extend UXON to encompass UX evaluation of other applications that record data in interaction logs.

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