Journal of the Brazilian Computer Society, 2025, 31:1, doi: 10.5753/jbcs.2024.4351

Unveiling the Use of Networked Ontologies to Develop a Supporting Tool for UX Evaluation in an Immersive Context

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Received: 04 April 2024 • **Accepted:** 18 October 2024 • **Published:** 17 February 2025

Abstract Immersive technologies have emerged as a new type of interactive system that aims to provide users with immersive experiences. They have been adopted in various fields and are gradually becoming part of our lives. UX is a key quality attribute to evaluate or model such experiences. However, when it comes to immersive experiences, evaluating UX is particularly challenging because the user should not be interrupted to provide feedback. Aiming at giving a step to address this issue, we have explored using ontologies from an ontology network to support evaluating immersive experiences. In this work, we adopted the Human-Computer Interaction Ontology Network (HCI-ON) and used an extract containing concepts from some of its networked ontologies to develop the User eXperience evaluation based on Ontology Network (UXON), an ontology-based tool that supports UX experts evaluating immersive experiences based on data recorded in interaction logs. HCI-ON is a framework for organizing knowledge of the HCI domain, offering a general understanding of the field, regardless of specific solutions. UXON was used to evaluate the UX of Compomus, an immersive application that supports collaborative music composition. UXON extracts data from the application interaction logs, calculates UX metrics, and provides consolidated data and information in graphs and tables. We conducted a study and collected feedback from the UXON 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, UXON was considered a promising system, beneficial, helpful, and easy to use. The conceptualization used to develop UXON was evaluated by HCI experts and it was considered adequate and understandable, having the potential to be used by other people to solve HCI evaluation problems.

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

1 Introduction

In today's digital world, effective interactive systems[1] are crucial. Their success hinges not only on their ability to deliver functionalities that meet the user needs, but also on the experience the system provokes in the users while interacting with it [Hassan and Galal-Edeen, 2017].

Designing and evaluating interactive systems for human use and the related phenomena are the main focus of the Human-Computer Interaction area (HCI) [Barbosa *et al.*, 2021]. HCI community values the quality of use [Hassan and Galal-Edeen, 2017] and develops and applies evaluation methods to assess it [Preece *et al.*, 2019; Carroll, 2014]. Usability and user experience (UX) have been recognized as determinants of the interactive system quality and indicators of system success or failure [Hassan and Galal-Edeen, 2017]. 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 [Hassan and Galal-Edeen, 2017].

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 [Barbosa *et al.*, 2021; Petrie and Bevan, 2009]. Usually, when evaluating UX, it is common to observe users in a certain activity [Pettersson *et al.*, 2018] or use questionnaires for users to self-report the experience. However, collecting data may not be

[1] In this paper, the term "interactive system" is adopted with the same meaning of "interactive computer system", i.e., a combination of hardware and software that receives input from and communicates output to users [ISO, 2019].

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 [Law *et al*., 2009]. UX is also understood in terms of its dimensions: Enjoyment/Fun, Motivation, Frustration, Engagement, and others [Pettersson *et al*., 2018]. 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 [Marques *et al*., 2020]). Thus, we can define metrics to collect data regarding the interaction and analyze user engagement [O'Brien *et al*., 2018].

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 [Feilmayr and Wöß, 2016]. 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 [Costa *et al*., 2020], to develop a tool that helps evaluate the UX in immersive technologies. Immersive technologies aim to engage [Marques *et al*., 2020] and create a sense of immersion for the user, to the point that the boundaries between the physical and virtual worlds are blurred [Suh and Prophet, 2018]. They include several types of technologies, such as virtual reality (VR), augmented reality (AR), mixed reality (MR), and mobile apps, among others [Suh and Prophet, 2018; Marques *et al*., 2020].

HCI-ON [Costa *et al*., 2020] 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 who 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.

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 uses networked ontologies from HCI-ON as a basis for the tool, which 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 that was very helpful, useful, and easy to use. Moreover, feedback provided by the UXON developer indicates that the use of networked ontologies greatly supported the tool's development. 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. It extends [Costa *et al*., 2024] by improving the paper background, introducing HCI-ON and its ontologies relevant to this work, and describing further details about UXON and the use of ontologies to develop it. We also detail the studies performed to capture UXON users' and developer feedback about the tool and the use of networked ontologies to develop it, and present the results (mainly qualitative) in full. Additionally, we present a new study performed to evaluate the conceptualization (i.e., the HCI-ON extract) used to develop UXON. The main contributions of this paper when compared to [Costa *et al*., 2024] are a more comprehensive presentation of HCI-ON, which helps understand the use of networked ontologies, and the new study, which provides (preliminary) evidence that the conceptualization used to develop UXON is adequate and understandable, having the potential to be used by other people to address HCI evaluation problems (e.g., standards harmonization, tool development, and communication, among others).

This paper contributes to researchers by proposing networked ontologies to address HCI evaluation aspects, exploring their use to build a solution related to HCI evaluation, and shining 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. Additionally, the conceptualization used to develop UXON can be used by other people in diverse HCI evaluation solutions.

The paper is organized as follows. Section 2 provides the background for the paper. Section 3 introduces HCI-ON and presents its fragment used to develop UXON. Section 4 introduces the problem. Section 5 presents UXON. Section 6 concerns the studies carried out to capture UXON users' and developer's perceptions. Section 7 presents the study performed to evaluate the conceptualization used to develop UXON. Section 8 discusses related work. Lastly, Section 9 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 [ISO, 2018], UX is more holistic [Nakamura *et al*., 2022; Barbosa *et al*., 2021; Hassan and Galal-Edeen, 2017; Hassenzahl, 2008].

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 [Pettersson *et al*., 2018]. UX has attracted increasing interest in recent years [Pettersson *et al*., 2018], extending the perspective on usability to less pragmatic, more hedonic, and non-task-oriented considerations about interactive systems [Hassenzahl and Tractinsky, 2006; Hassenzahl, 2008].

In UX research, evaluation is one of the core pillars [Pettersson *et al*., 2018]. Evaluating UX is challenging because users may have trouble expressing their experiences if directly asked to [Rivero and Conte, 2017]. 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 blurs the boundary between the physical and virtual worlds and enables users to experience new sensations, such as immersion [Suh and Prophet, 2018].

There are methods in which UX evaluation is based on user observation [Petrie and Bevan, 2009], which allows the recording of interaction data and measurement of collected data [Barbosa *et al*., 2021] to reach conclusions about these characteristics of quality of use. Observation ensures that the user is not interrupted during their interaction experience [Preece *et al*., 2019]. 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 [Barbosa *et al*., 2021; Preece *et al*., 2019; Petrie and Bevan, 2009]. In both, data from interactions and situations that may occur while the user interacts with the system are recorded and analyzed (or measured) and allow identifying problems during the user experience [Barbosa *et al*., 2021; Preece *et al*., 2019].

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 [Preece *et al*., 2019; Petrie and Bevan, 2009].

A metric[2] allows characterizing a particular entity by quantifying its properties [Barcellos *et al*., 2010]. Thus, metrics related to UX quantitatively describe some perspectives of this experience [Albert and Tullis, 2013]. 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). In our work, metrics are applied to data from interaction logs to quantify UX in the immersive context (details in Section 4).

2.2 Ontology and Ontology Network

An ontology is a formal and explicit specification of a shared conceptualization [Studer *et al*., 1998]. 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 [Staab and Studer, 2004].

According to Scherp *et al*. [2011], ontologies can be classified into foundational, core, and domain generality levels. *Foundational ontologies* aim at modeling the very basic and general concepts and relations that make up the world (including domain-independent notions, such as objects, events, participation, and parthood) [Guarino, 1998]. They are generic across any area, highly reusable in different modeling scenarios (domain-independent), and represent the highest-level ontologies. *Core ontologies* provide a refinement to foundational ontologies by adding detailed concepts and relations in a specific area (such as service, process, organizational structure) that still spans across various (sub)domains. Core ontologies are situated in between foundational and domain ontologies and, despite being more general than domain ontologies, are domain-dependent. Finally, *domain ontologies* describe knowledge that is specific to a particular domain (e.g., an ontology about the anatomy of the human body)and represent the lowest-level ontologies. They can make use of/be based on foundational ontologies or core ontologies by specializing their concepts.

Another important distinction differentiates ontologies as conceptual models, called *reference ontologie*s, from ontologies as computational artifacts, called *operational ontologies* [Guarino *et al*., 2009; Guizzardi, 2007]. 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) [Happel and Seedorf, 2006]. 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) [Happel and Seedorf, 2006]. When developing the tool proposed in this work, reference ontologies supported ODD and operational ontologies supported OBA (details in Section 5).

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

Specially for a complex domain (such as HCI), representing its knowledge as a single ontology results in a large and monolithic ontology that is hard to manipulate, use, and maintain [Suárez-Figueroa *et al*., 2012]. On the other hand, representing each sub-domain in isolation is a costly task that leads to a very fragmented solution that is again hard to handle [Ruy *et al*., 2016]. In such cases, building an *ontology network* (ON) is an adequate solution [Suárez-Figueroa *et al*., 2012; Ruy *et al*., 2016].

An ON is a collection of ontologies, included in such a network, related together through a variety of relationships, such as modularization, alignment, and dependency, sharing concepts and relations with other ontologies. Accordingly, a *networked ontology* is an ontology included in the network, sharing relationships with a potentially large number of other ontologies and, thus, forming a network of interlinked semantic resources [Suárez-Figueroa *et al*., 2012; Costa *et al*., 2020].

ONs enable to establish a comprehensive conceptualization that provides a common understanding of the domain and can be used as a reference to solve semantic interoperability and knowledge problems related to the conceptualization as a whole or to extracts of it. Hence, integrating several ontologies into an ON provides a framework that can be explored to potentialize and increase the set of solutions in the universe of discourse addressed by the ON [Ruy *et al*., 2016; Costa *et al*., 2020].

Developing an ON may require effort (particularly at the beginning, if existing ontologies need to be put in correspondence, merged, integrated, etc.). However, the effort is worth it because the ON potentializes knowledge reuse and growth and, as a consequence, promotes more robust and comprehensive ontology-based solutions. Moreover, if ontologies are organized in an ON, when ontologies are needed in scenarios spanning different sub-domains, instead of spending effort to integrate several ontologies, one can just extract the ON portion to be used [Costa *et al*., 2020].

In the work described in this paper, we used networked ontologies of HCI-ON [Costa *et al*., 2020], an HCI ontology network that is introduced in the next section.

3 The Human-Computer Interaction Ontology Network (HCI-ON)

The Human-Computer Interaction Ontology Network (HCI-ON) is a knowledge framework of HCI that provides a general and solution-independent conceptualization resulting from an intensive HCI domain analysis [Costa *et al*., 2020, 2022; Costa, 2022]. 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) [Guizzardi, 2005], 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.

Figure 1 presents an overview of HCI-ON current version. In the figure, each circle represents an ontology. Dotted circles represent HCI-ON ontologies under development. Arrows denote the dependency relationship between networked ontologies. The dependency relationship indicates that concepts from the target ontology are reused by the source ontology.

HCI-ON addresses HCI core aspects and sub-domains, adopting an architecture that promotes knowledge organization. HCI-ON adopts a three-layered architecture by following the classification proposed in [Scherp *et al*., 2011]. In the background, we have a foundational ontology (the Unified Foundational Ontology – UFO [Guizzardi, 2005; Guizzardi *et al*., 2008, 2013]) to provide the general ground knowledge for classifying concepts and relations in the ON[3]. In the center, core ontologies are used to represent the general domain knowledge, being the basis for the sub-domain networked ontologies. Last, domain-specific ontologies appear, describing more specific knowledge.

In a nutshell, the foundational layer offers the ontological distinctions for the core and domain layers, while the core layer offers the HCI core knowledge for building the domain networked ontologies. This way of grounding the ontologies in the network is helpful for engineering the networked ontologies, since it provides ontological consistency and makes several modeling decisions easier, contributing to knowledge grounding and consistency. Moreover, HCI is a very interrelated domain and, as HCI-ON increases, it has more ontologies with concepts and relations potentially reusable by the new ontologies. This reuse-based development promoted by the ON contributes to knowledge growth.

Currently, HCI-ON includes ten ontologies and more than 100 concepts. At the core layer, there is the *Human-Computer Interaction Ontology* (HCIO), which addresses what an interactive computer system is, user actions taken in an interaction, and how an interaction happens [Costa *et al*., 2022]. There is also the *Core Ontology on Measurement* (COM) [Barcellos *et al*., 2014], which addresses core concepts related to measurement and is an external core ontology (in the sense that it is not devoted to the HCI domain) that was integrated into HCI-ON during this work. At the domain layer, there are nine ontologies, namely: *User Characterization Ontology* (UCO), which concers aspects related to user characteristics; *UI Types and Elements Ontology* (UIT&EO), which addresses UI types and its components; *Adaptive Interface Ontology* (AIO), which deals with AUI, its components and customizations; *User Profile Ontology* (UPO), which addresses general aspects of the user profile and useful information for managing and improving interface adaptations; *Context of Use Ontology* (CUO), which involves concepts describing the elements that characterize a context of use, such as physical and social environments wherein the interaction occurs; *HCI Modality Ontology* (HCIMO), which treats HCI styles/paradigms (modalities of interaction); *HCI Qual-*

[3] Dicussions about UFO and its use to ground HCI-ON core and domain ontologies are out of the scope of this paper. Information about that can be found in [Costa *et al*., 2020, 2022; Costa, 2022].

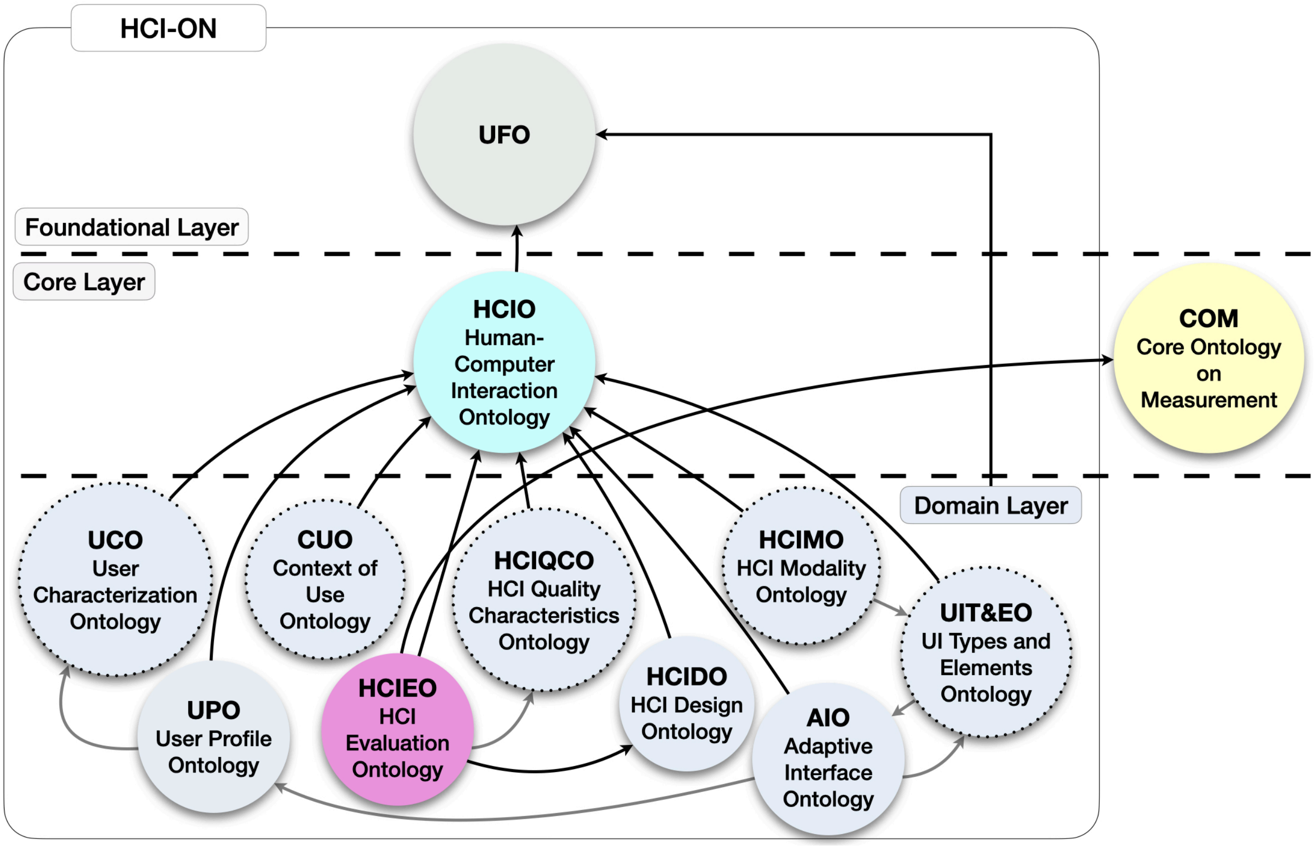


Figure 1. HCI-ON current version.

ity Characteristics Ontology (HCIQCO), which concerns interactive computer system quality characteristics (e.g., usability, communicability); *HCI Design Ontology* (HCIDO), which involves concepts related to HCI design and design components [Costa *et al.*, 2020; Castro, 2021]; and *HCI Evaluation Ontology* (HCIEO), which was developed in the context of this work and regards concepts related to HCI evaluation and measurement.

HCI-ON allows the use of the complete framework or extracts of it. Since the concepts are integrated consistently, one can just select the fragment that reflects the domain of interest [Costa *et al.*, 2020; Costa, 2022].

In Figure 2, we present the HCI-ON extract relevant to this paper (for simplification reasons, UFO concepts are not shown). To select the fragment, we considered the HCI domain portion that should be addressed by the tool. For that, we first studied the problem to be treated (described in Section 4). Then, we thought about the solution we should develop and identified the involved subjects (e.g., HCI evaluation, measurement, interactive computer system) and selected the HCI-ON's ontologies related to them. Lastly, we analyzed the ontologies and identified the concepts we needed. The HCI-ON extract used represents the conceptualization behind UXON and contains concepts from three HCI-ON networked ontologies, namely: the *Human-Computer Interaction Ontology* (HCIO) [Costa *et al.*, 2022], which regards the core conceptualization about the interaction between user and interactive computer system, addressing concepts such as User, User Participation, Human-Computer Interaction; the *Human-Computer Interaction Evaluation Ontology* (HCIEO), which addresses several aspects and different kinds of HCI evaluation, involving concepts such as HCI Evaluator, HCI Evaluation Report, and HCI Evaluator, among others; and the *Core Ontology on Measurement* (COM) [Barcellos *et al.*, 2014], which includes concepts such as Measure, Measurement, and Measured Value.

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. For such discussion, the reader should refer to [Costa, 2022].

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 2).

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 rel-

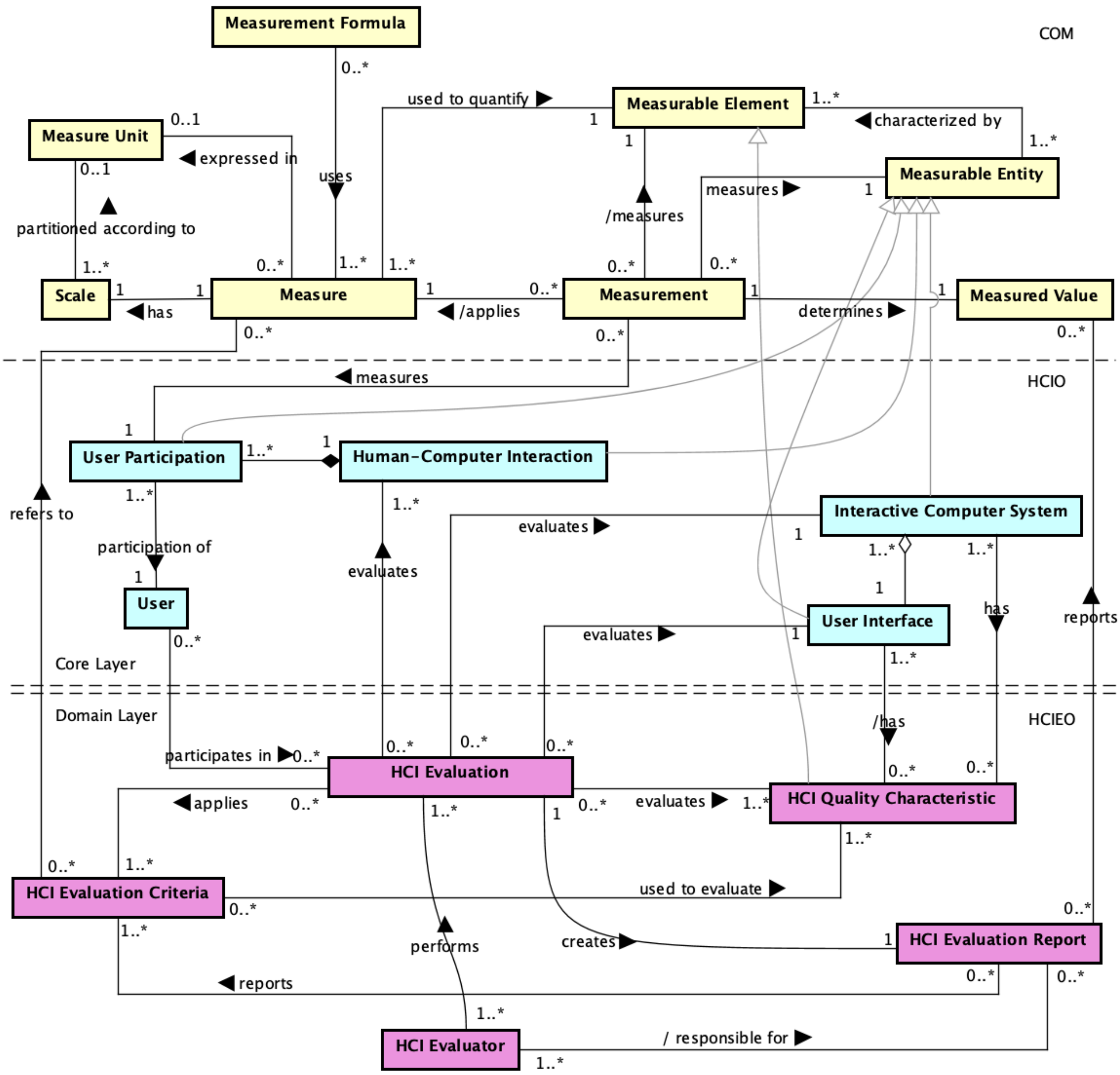


Figure 2. HCI-ON extract.

evant 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 of 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 Section 4 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*.

4 Understanding the Problem

Compomus [Amazonas *et al*., 2019; Marques *et al*., 2020] 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 3). 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 a 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 3). For each person and each movement or sound choice in this environment, *Compomus* records in an interaction log file (Figure 4) the following data: *person*, *x*, *y*, *z*, *time*, *hour* and *sound* (first line of Figure 4).

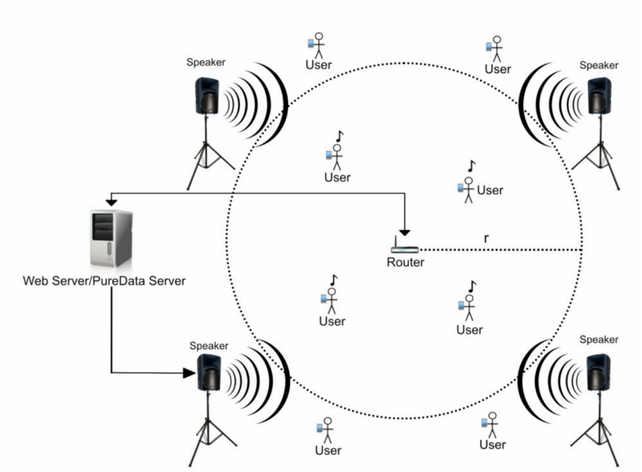
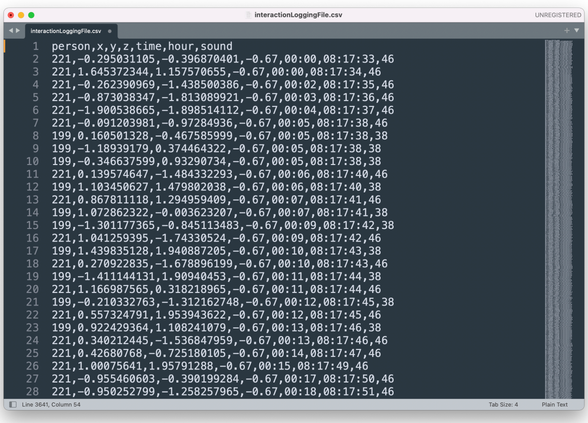


Figure 3. *Compomus* environment. Adaptated from [Amazonas *et al.*, 2019].



```
interactionLoggingFile.csv
1  person,x,y,z,time,hour,sound
2  221,-0.295031105,-0.396870401,-0.67,00:00,08:17:33,46
3  221,1.645372344,1.157570655,-0.67,00:00,08:17:34,46
4  221,-0.262390969,-1.438500386,-0.67,00:02,08:17:35,46
5  221,-0.873038347,-1.813089921,-0.67,00:03,08:17:36,46
6  221,-1.900538665,-1.898514112,-0.67,00:04,08:17:37,46
7  221,-0.091203981,-0.97284936,-0.67,00:05,08:17:38,46
8  199,0.160501328,-0.467585999,-0.67,00:05,08:17:38,38
9  199,-1.18939179,0.374464322,-0.67,00:05,08:17:38,38
10 199,-0.346637599,0.93290734,-0.67,00:05,08:17:38,38
11 221,0.139574647,-1.484332293,-0.67,00:06,08:17:40,46
12 199,1.103450627,1.479802038,-0.67,00:06,08:17:40,38
13 221,0.867811118,1.294959409,-0.67,00:07,08:17:41,46
14 199,1.072862322,-0.003623207,-0.67,00:07,08:17:41,38
15 199,-1.301177365,-0.845113483,-0.67,00:09,08:17:42,38
16 221,1.041259395,-1.74330524,-0.67,00:09,08:17:42,46
17 199,1.439835128,1.940887205,-0.67,00:10,08:17:43,38
18 221,0.270922835,-1.678896199,-0.67,00:10,08:17:43,46
19 199,-1.411144131,1.90940453,-0.67,00:11,08:17:44,38
20 221,1.166987565,0.318218965,-0.67,00:11,08:17:44,46
21 199,-0.210332763,-1.312162748,-0.67,00:12,08:17:45,38
22 221,0.557324791,1.953943622,-0.67,00:12,08:17:45,46
23 199,0.922429364,1.108241079,-0.67,00:13,08:17:46,38
24 221,0.340212445,-1.536847959,-0.67,00:13,08:17:46,46
25 221,0.42680768,-0.725180105,-0.67,00:14,08:17:47,46
26 221,1.00075641,1.95791288,-0.67,00:15,08:17:49,46
27 221,-0.955460603,-0.390199284,-0.67,00:17,08:17:50,46
28 221,-0.950252799,-1.258257965,-0.67,00:18,08:17:51,46
Line 3641, Column 54
```

Figure 4. Fragment of *Compomus* interaction log file.

Person refers to the participant ID. Data from *x*, *y* and *z*[4] together refer to the *Person's geolocation* in the music composition environment. *Time* refers to the duration of the session until the data record. *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 [Marques *et al.*, 2020]:

- *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:

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

[4] 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*.

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., [Santos Júnior *et al*., 2021; Nagel *et al*., 2021; Calero *et al*., 2006]) and the promising use of networked ontologies [Ruy *et al*., 2016], we decided to use ontologies from HCI-ON to develop UXON to support UX evaluation.

5 UXON: User eXperience evaluation based on Ontology Network

An overview of UXON is shown in Figure 5. 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[5]. 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.

The development of UXON was based on the HCI-ON extract presented in Section 3 and followed the Ontology-Driven Development (ODD) and Ontology-Based Architectures (OBA) approaches [Happel and Seedorf, 2006]. 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[6]. 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[7] 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 6 shows the resulting conceptual model. Dotted lines separate concepts based on different HCI-ON ontologies at the same layer. Doubled dotted lines separate concepts based on ontologies from different layers..

Next, we discuss how data from the interaction log file (see an example in Figure 4) was mapped to UXON conceptual model. The interaction log header (first line of the log) was mapped to concepts and/or attributes. For example, a *person* is a user (*User*) who has an identifier (*user_id*). The sound change and the geolocation change performed by a person when interacting with the application are interactions of that person and, thus, participation events (i.e., *User Participation*). The *sound*, *time*, *x*, *y,* and *z* are properties of the interaction and, thus, were mapped as *User Participation* attributes created to store data about the user participation: *up_sound* (identifier of the emitted sound), *up_timestamp* (instant in time in which the interaction occurred), *up_geolocation_x*, *up_geolocation_y*, and *up_geolocation_z* (person's geolocation).

The *Human-Computer Interaction* concept represents the set of all interactions of a person in a music composition session (i.e., all *User Participations* of that *User* in that session) and contains time and duration attributes of the session (*hci_start_time*, *hci_end_time* and *hci_pduration*). This information is obtained from the log using the time of the first and last interactions of the session. It is necessary to calculate the interactivity metric. The *hci_start_time* attribute stores the time the session started, which is recorded in the second line of the log. The *hci_end_time* attribute stores the time the session ended, which is recorded in the last line of the

[5] 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.

[6] 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 [Carraretto and Almeida, 2012].

[7] 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.

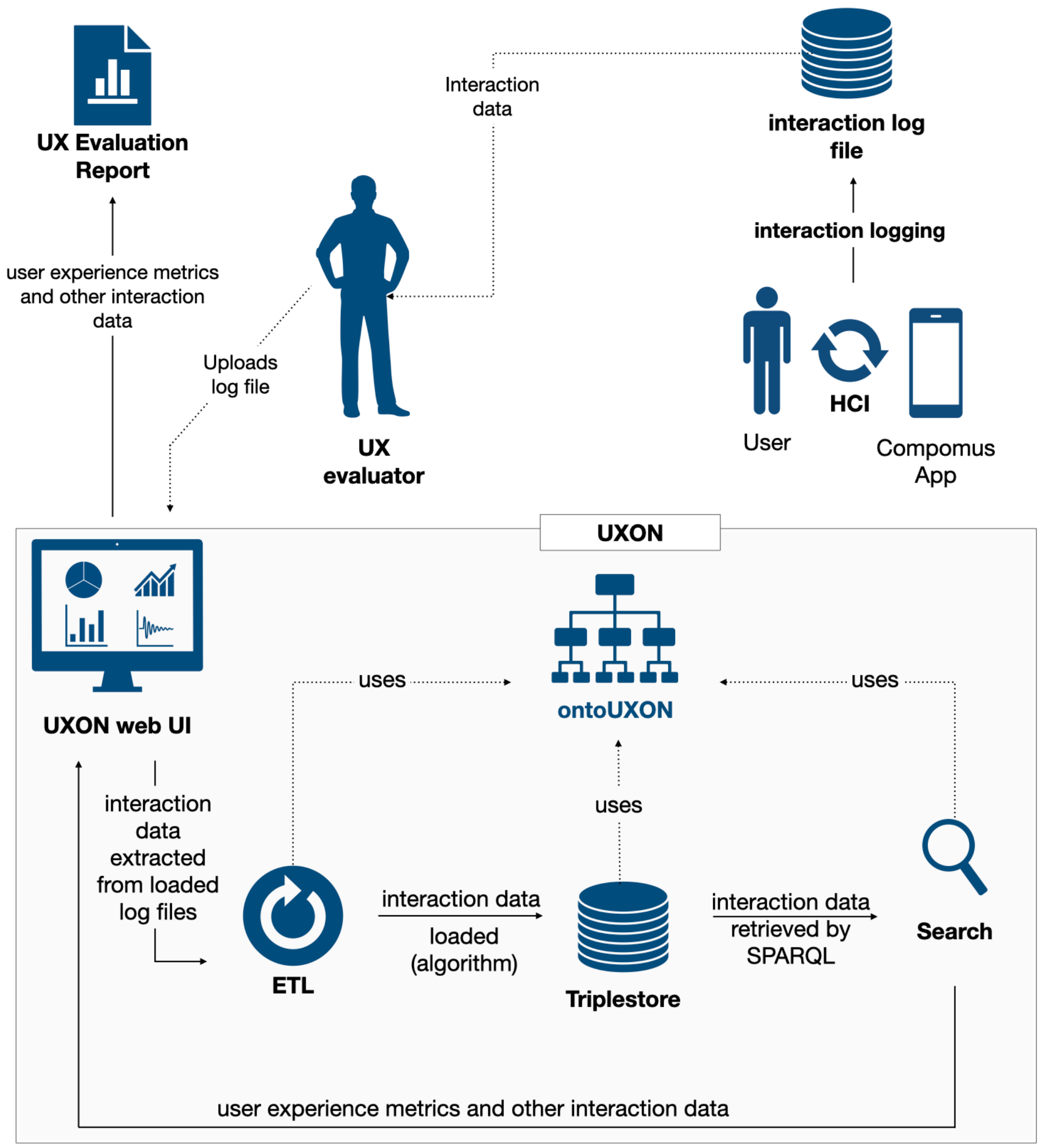


Figure 5. UXON overview.

log. The difference between the end time and the start time is the session duration, which is recorded in the *hci_pduration* attribute.

The other concepts in the conceptual model do not have a direct mapping with data from the interaction log. They represent concepts necessary to store data required to carry out measurement-based UX evaluation, and the adjustments made in this context were explained above.

5.2 ontoUXON Operational Ontology

From UXON conceptual model, we created ontoUXON, by transcribing the model to OWL using the Protegé[8]. Figure 7 presents fragments of ontoUXON code.

In Figure 7, lines 3 to 9 present an excerpt from the OWL code referring to the *Measurement* and *User* classes (concepts) of the UXON conceptual model. Lines 11 to 17 regard the *is_measured_by* (object property) relationship between the *UserParticipation* and *Measurement* classes, and its inverse relationship *measures*. Finally, lines 19 to 15 concern the attribute (data property in OWL) *mt_measured_value* of the *Measurement* class of the UXON conceptual model and define its data type as *decimal*.

Semantic Web technologies (OWL, RDF, etc.) allow representing knowledge in RDF triple [Subject → Predicate (or "Property") → Object] and RDF graph. Figure 8 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#`.

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.`

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

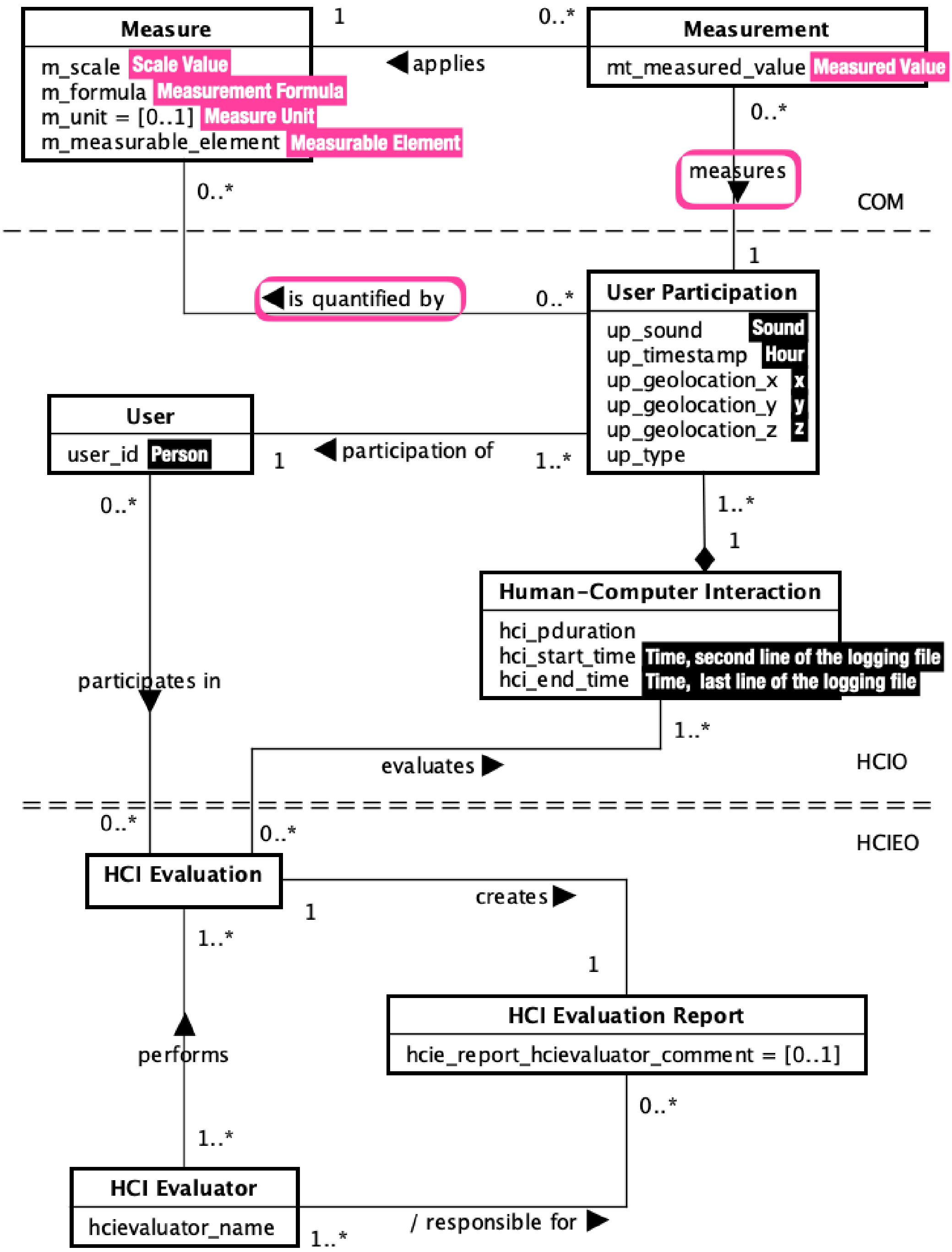


Figure 6. UXON conceptual model.

`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[9] 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 (Figure 9) 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 10 illustrates bar charts showing data regarding *in-*

[9]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 [W3C, 2015].

```
<!--  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 7. Fragment of ontoUXON.

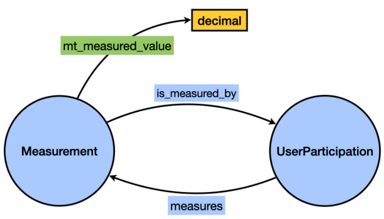


Figure 8. RDF graph.

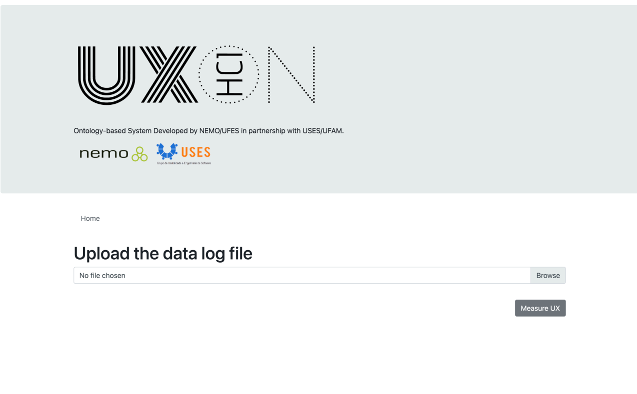


Figure 9. UXON's home page.

teractivity, *interaction*, and *percentage of interactions* considering all users that participated in the session. Data can also be visualized in a table, as illustrated by Figure 11.

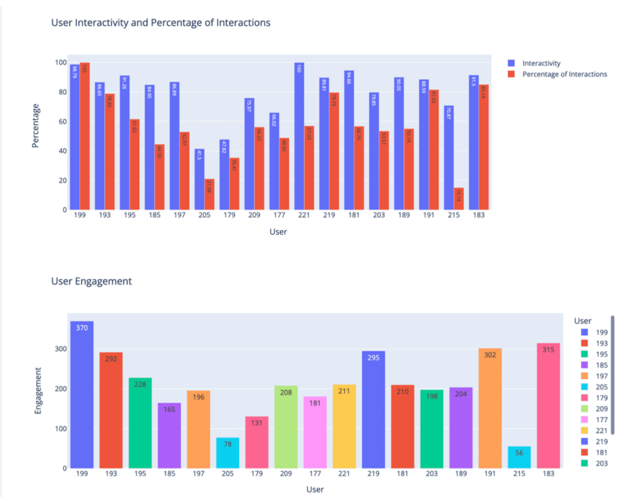
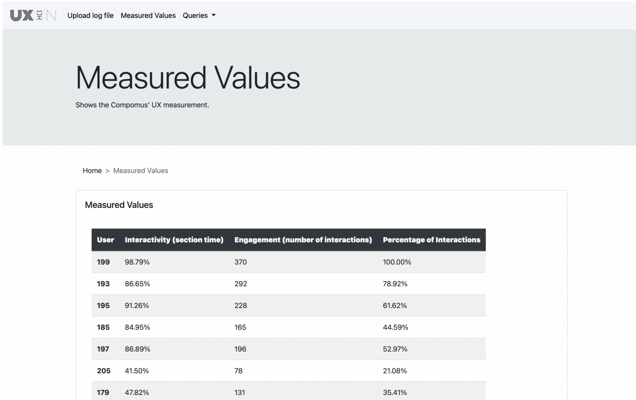


Figure 10. Bar charts with UX metrics related to all users.



User	Interactivity (section time)	Engagement (number of interactions)	Percentage of Interactions
199	98.79%	370	100.00%
193	86.65%	292	78.92%
195	91.26%	228	61.62%
185	84.95%	165	44.59%
197	86.89%	196	52.97%
205	41.50%	78	21.08%
179	47.82%	131	35.41%

Figure 11. Values calculated for UX metrics shown in table format.

Additionally, Figure 12 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.

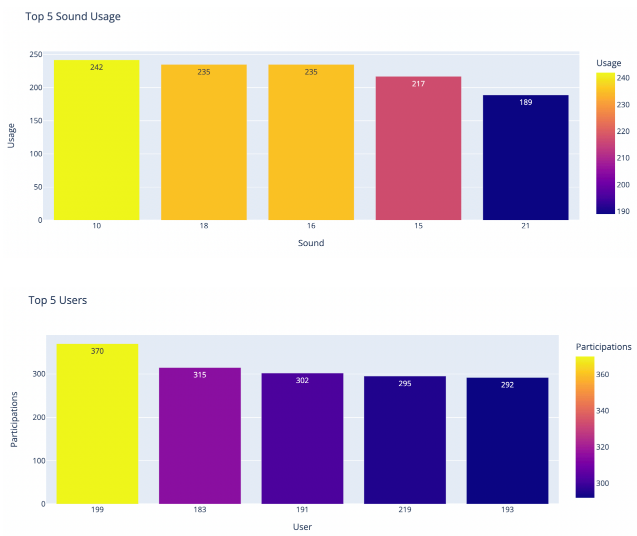


Figure 12. Top 5 sounds and users.

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 13) or dynamic (Figure 14) perspective (i.e., the points move in the graph according to the user movements during the session). Furthermore, these graphs can be generated for each user (i.e., it is possible to visualize the behavior of a single user that participated in the session) or for all the users that participated in the session (i.e., it is possible to visualize the behavior of all users at the same time).

In addition to several tables and graphs to visualize metrics values and complementary information, UXON also pro-

Figure 13. User interaction (static perspective).

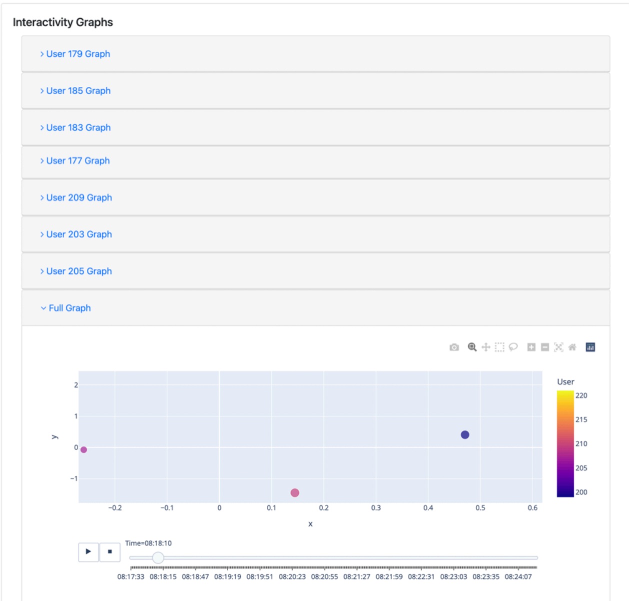


Figure 14. Users interaction (snapshot of the dynamic perspective) .

vides 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).

Figure 15 shows the page where the evaluator accesses predefined queries. The figure shows two queries. The first one (*Sound Change Interaction*) is related to the participants' sound change interactions (i.e., how many times the user changed the sound during the session). The UX evaluator can search for the sound change interactions of a single user or of all the users who participated in the session. The results are presented in a table and a geolocation graph (Figure 16). The second query (Figure 15, *Sound Usage*) is related to the sounds used during the session and allows the UX evaluator to verify the emitted sounds, the users who emitted them, and how many times a sound was emitted by each user or by all users.

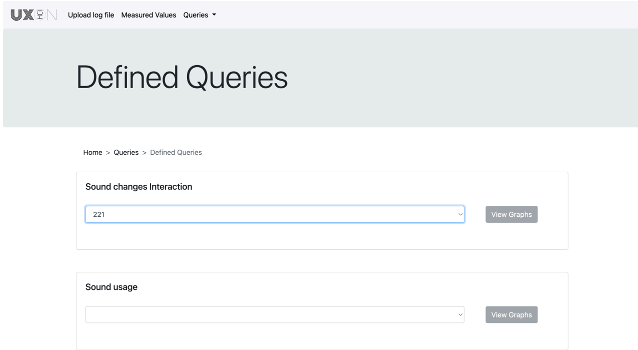


Figure 15. Defined Queries page.

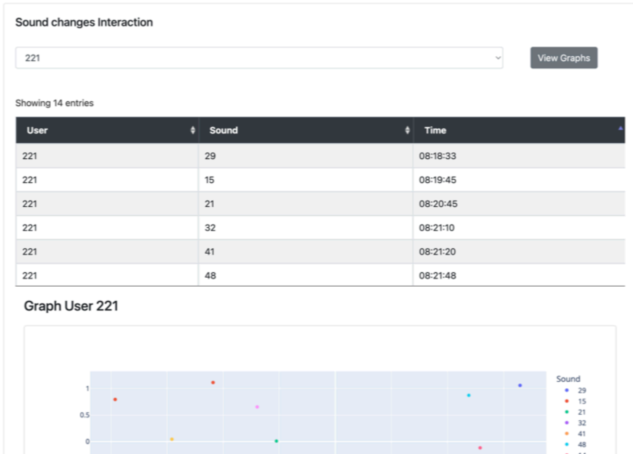


Figure 16. Defined Queries page results.

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 17 illustrates a piece of the custom queries page containing a query created by the UX evaluator to list all the interactions of a user. Figure 18 presents the results shown in a table (for user 183).

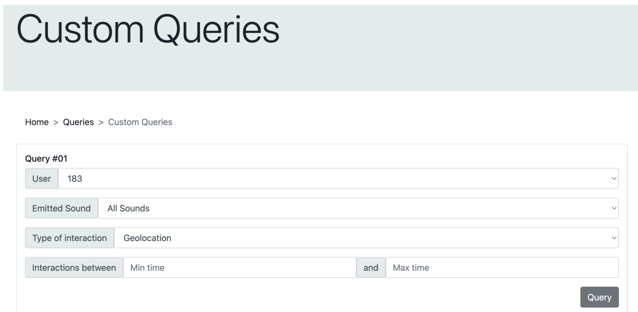


Figure 17. Custom Queries page.

Finally, after analyzing data about the user interactions, the UX evaluator records their analysis and conclusions in an Evaluation Report and can download a PDF file containing all graphs and tables considered in the evaluation plus the evaluator's comments. Figure 19 depicts the screen in which the evaluator inputs their comments and can download the evaluation report.

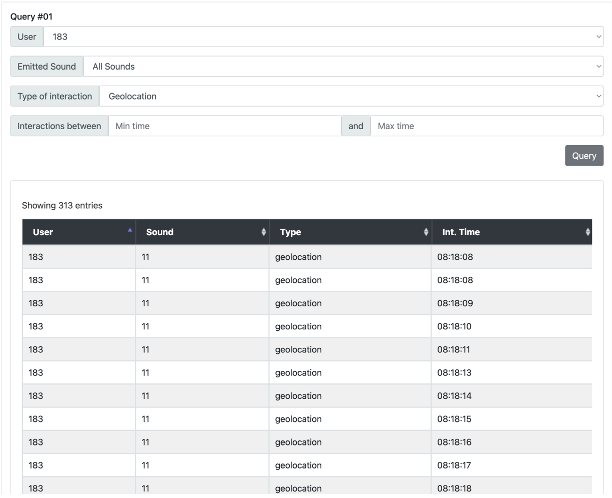


Figure 18. Custom Queries page results.

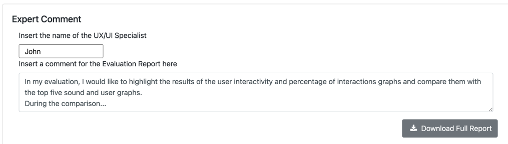


Figure 19. Evaluation Report screen.

6 UXON Evaluation

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 the user (Section 6.1) and developer (Section 6.2) perspectives. The studies were approved by The Ethics Committee of the Federal University of Amazonas (UFAM), with registration number (CAAE): 51490121.0.0000.5020.

6.1 User Perspective

This section presents the study carried out with UXON users, which enabled us to find preliminary evidence to evaluate and improve UXON in terms of its usefulness and the feasibility of using it. Section 6.1.1 presents the study design; Section 6.1.2 addresses its execution and main results; in Section 6.1.3, we discuss the results; and Section 6.1.4 concerns the threats to validity.

6.1.1 Study Design

The study ***goal*** was to verify whether an extract of HCI-ON (i.e., networked ontologies) can be used to produce a suitable solution for an HCI-related problem. Following the GQM approach [Basili *et al*., 1994], this goal is formalized as follows:

Analyze UXON
With the purpose of verifying if it is a suitable solution for evaluating Compomus UX[10]
Regarding its usefulness and feasibility
From the point of view of UX evaluators
In the context of UX evaluation by using interaction logging information.

To analyze the results, the following *indicators* were considered: usefulness and feasibility. The former was evaluated based on the perceptions of the UX evaluators of how much UXON helped them evaluate UX. The latter was evaluated based on the perceptions of the UX evaluators of how much ease and feasible they considered using UXON. The benefits and drawbacks pointed by the participants were also considered to indicate if UXON is useful and feasible.

The ***instruments*** used in the study consisted of: (i) a consent form to participate in the study, which aimed to safeguard the participants' rights regarding the study and its results; (ii) a form to characterize the participants' profile, which aimed to obtain information about the participants' knowledge of and experience in HCI evaluation; and (iii) a questionnaire that allowed participants to record their perception after using UXON. The forms were prepared using Google Forms and are available in [Costa and Barcellos, 2024b].

The ***participants*** were the three UX evaluators 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.

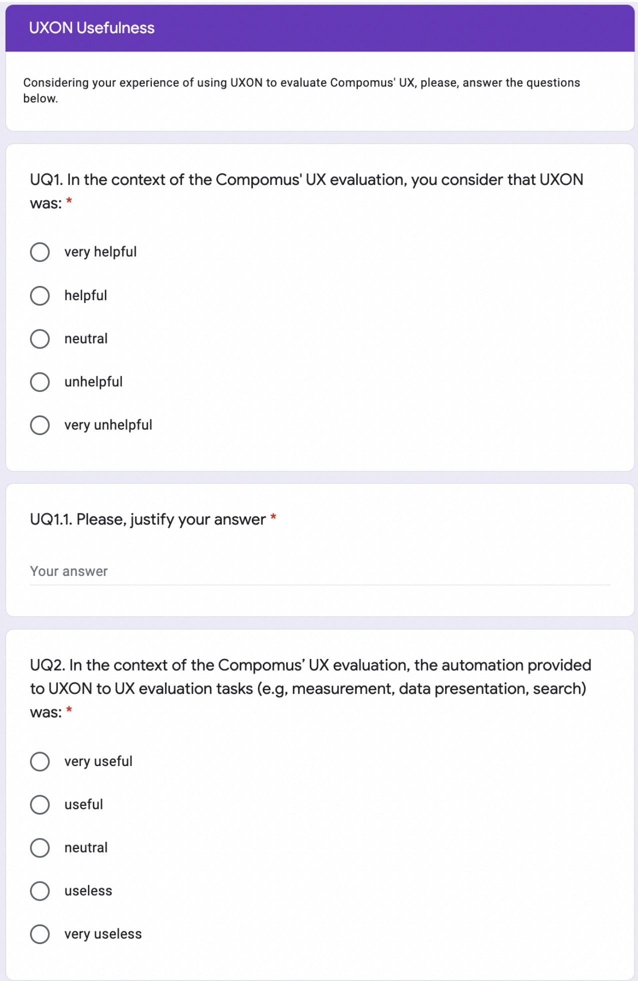
The ***procedure*** adopted in the study consisted of making a brief presentation about UXON to the study participants and making UXON available for use for around 30 days. After that, the three participants were invited via email to answer a questionnaire. After all of them accepted the invitation, the questionnaire was made available for 15 days. The provided answers were, thus, analyzed according to the study goal.

The questionnaire included 12 objective questions, whose possible answers are based on Likert scale. For each of them, the participants were asked to justify their answers. There was also a subjective question in which the participants could provide general improvement suggestions to UXON. The questionnaire was organized into three sections, namely: UXON Usefulness (7 questions); UXON Feasibility (4 questions); and, UXON General Evaluation and Suggestions (4 questions). A fragment of the questionnaire is presented in Figure 20. The form is available in [Costa and Barcellos, 2024b].

6.1.2 Study Execution and Results

The participants of the study will be referred to as P1, P2, and P3. Concerning their profile, P1 and P2 were Ph.D students

[10]The term UX, when referring to Compomus' UX throughout the text, refers to the immersive experience provided through the use of Compomus during a music composition session.


UXON Usefulness

Considering your experience of using UXON to evaluate Compomus' UX, please, answer the questions below.

UQ1. In the context of the Compomus' UX evaluation, you consider that UXON was: *

- very helpful
- helpful
- neutral
- unhelpful
- very unhelpful

UQ1.1. Please, justify your answer *

Your answer

UQ2. In the context of the Compomus' UX evaluation, the automation provided to UXON to UX evaluation tasks (e.g, measurement, data presentation, search) was: *

- very useful
- useful
- neutral
- useless
- very useless

Figure 20. Fragment of the questionnaire.

who declared to have, respectively, high and medium theoretical knowledge of and practical experience in UX Evaluation. P3 was a senior researcher who has a Ph.D degree and declared to have high theoretical knowledge of and practical experience in UX Evaluation.

Following the planned procedure, the participants used UXON for about 30 days to evaluate Compomus UX considering data from several sessions. After that, they answered the questionnaire. Next, we summarize the main results obtained from the participants' answers and comments.

UXON Usefulness

All the participants considered UXON *very helpful* to *evaluate Compomus UX*. According to P1, UXON plays an important role in supporting the analysis of UX data and automates a process that could take longer. P2 pointed out that the system is capable of plotting graphs from very large log files, which is challenging even for those who have some affinity with data processing systems. P3, in turn, emphasized that UXON offers useful metrics and graphs to analyze how *Compomus* users interacted and engaged.

All participants also considered the *automation provided to UXON* to UX evaluation tasks (e.g., measurement, data presentation, search) *very useful*. P1 stressed that data presentation is excellent, avoids more extensive analysis work, and allows analyzing individual data, which previously required a lot of effort. P2 stated that UXON reduced the time to obtain the desired information. P3, in turn, pointed out that UXON allows visualizing information in a simple way and that graphs and statistics are easy to analyze.

When asked to compare *data presentation* provided by UXON to the one provided by the previously used solution, two participants (P2 and P3) declared that UXON *improved* data presentation and one (P1) declared that UXON *strongly improved* it. P1 pointed out that prior to UXON there was no standard solution, and this was a problem. P3 added that they used Google Collaboratory and that everything was very rudimentary, and required a lot of effort to calculate the metrics. P2 highlighted that UXON provides dynamic and editable graphics that help demonstrate more personalized graphics. P3 added that UXON's graphs facilitate the visualization of data and compare the interaction between the participants visually.

When asked to compare *the quality of data analysis* (based on the collected data) and *reached conclusions* provided by UXON to the one provided by the previously used solution, two participants (P1 and P3) declared that UXON *strongly improved* the quality of data analysis and reached conclusions and one (P2) declared that UXON *improved* them. P2 pointed out that UXON supported new points of view from the data and P3 said that UXON facilitated and simplified data analysis, mainly by presenting graphical representations of the interactions.

All the participants considered UXON *neutral* regarding the improvements in the Compomus' UI/UX. All participants mentioned that it may be difficult to identify improvement opportunities based on the available log data.

When asked to compare the *time and effort spent* to evaluate Compomus' UX, using UXON and the previous solution, all participants considered that UXON *strongly decreased* them. P1 and P2 said that using UXON saved time and effort. P3 emphasized that it was much easier to perform the analysis with 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 emphasized that due to the interactive graphics, there is a delay in data processing and that at this stage, a more visible loading message would fit for the evaluator to know that the data is being processed.

All participants considered that UXON *strongly supports data analysis & results* (e.g., data visualization, reaching conclusions) and *does not support* planning (e.g., definition of the metrics to be used) activities during a UX evaluation. Data collection (e.g., data capture, formatting, and storage) activity was considered to be *strongly supported* by one (P3) participant and *not supported* by two (P1 and P2). P1 and P2 justified that planning and data collection activities are not supported, as UXON was not built for that purpose. P3 highlighted that UXON does not help in planning new metrics, as the metrics used are fixed. P1 stressed that UXON is extremely important for data analysis, P2 added that UXON helped in analyzing the data and reaching conclusions. P3 added that for data collection and analysis, UXON helps a lot.

UXON Feasibility

All participants found UXON *easy to use*. P2 justified his answer by saying that some graph customizations are not easy to perceive.

Regarding the *terminology* used in UXON, two participants (P1 and P3) considered it *very consistent* with the application domain (UX evaluation) and one (P2) found it *consistent*. P2 said that it is consistent only for those who are familiar with UX.

When asked if they would *use UXON again*, all participants answered *yes*. P1 explained that as an evaluator, UXON exponentially facilitated his job. P2 stated that UXON reduces work and time. P3 emphasized that they will use UXON whenever he needs to evaluate music composition session data and Compomus UX.

Concerning *recommending UXON for other people*, P1 and P2 answered that they *would*, while P3 said that he *would not*, because UXON is specific to evaluate Compomus UX and other people may not be interested in evaluating that application.

General Aspects

When asked about *extending UXON to support UX evaluation of other applications* whose evaluation is based on interaction logging data, all participants considered that it would be *very useful*. P1 emphasized that evaluating UX through log file's data is a big challenge, therefore, the role of UXON is fundamental. P2 added that it would be very valid, as the analysis of large volumes of data requires knowledge of several programming languages and that the data can be analyzed more easily by a ready-made system. P3 emphasized that UXON would help evaluators work with the log files of other applications in an easy way, providing useful information and easy analysis.

Regarding the main *advantages* of using UXON, the participants listed: support in the analysis process; visual analysis of data; analysis by participant and overall experience; individual analysis of UX metrics for the immersive experience, allowing conclusions regarding the experience; practicality; ease of use; simplicity in the process of loading log files; graphical presentations that make it possible to have an overview of the interaction; diversity of forms of data organization (different graphics); and possibility of performing new queries.

As for the main *disadvantages* of using UXON, the participants cited: data processing time; graphic quality of the evaluation report; preparing log file as input without knowing the data format of the database expected by the system; and UXON only works for Compomus.

Finally, when asked about *suggestions* for UXON improvement, the participants answered: improve data processing time; make some graphs more explanatory; improve the layout of the data/graphics presentation; provide documentation that informs which fields are required and expected by the system for the evaluator to prepare its log file; and, offer help in creating new queries.

6.1.3 Discussion

In this section, we make some discussions about the results presented in the previous section in terms of the indicators established in the study planning.

Concerning *usefulness*, we observed that, in general, all participants had the same or a very close perception. They agreed that UXON is very helpful, useful, automates UX evaluation tasks, improves the quality of data presentation and data analysis, and strongly decreases time and effort spent to evaluate Compomus UX. They also agreed that the use of UXON was neutral to help identify improvements, when compared to the previous solution. We believe that this is due to the metrics currently available, which may be not enough to provide information to suggest improvements in Compomus UX. There is an ongoing doctorate research investigating UX/UI measures, thus new metrics can be added to UXON in the future, to provide a more comprehensive view of UX aspects and contribute more effectively to identifying improvement opportunities.

Regarding the UX evaluation process, the participants agreed that UXON strongly supports data analysis and does not support evaluation planning. The participants disagreed on the support for data collection. We believe that this is due to a different understanding of the data collection scope in the Compomus – UXON context. P1 and P2 (Ph.D students) considered that data collection is performed by Compomus, since it records interaction data in the log file. On the other hand, P3 (the most experienced participant) considered that data collection is supported by the ETL process, which captures data from the log file, stores it in UXON database and uses it to calculate the metrics values.

Regarding *feasibility*, the participants agreed that UXON is easy to use. Moreover, they would use UXON again and most of them would recommend UXON to other people. P3 said that he would not recommend it because UXON is specific to evaluate Compomus UX and other people may not be interested in that. Although this does not exactly represent a limitation, as the system was developed to specifically support Compomus, it points to the need to evolve UXON to handle data from other applications.

As for UXON terminology, the participants agreed that it is consistent with the application domain (UX evaluation) but P2 mentioned that the terminology is only suitable for those who are familiar with the UX domain. We understand the participant's concern. However, considering that the terminology is for a specific domain, it should be consistent with that domain. Thus, it is expected that people not familiar with that domain may use other terms and not know some terms often used in the domain. Thus, we believe that the terminology meets the main stakeholders' needs, and its suitability for other audiences would require further investigation.

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's quality, and the fact that UXON only works for Compomus. These limitations will be considered in future improvements. We agree that we need to reduce processing time and show the processing progress to the user until it is finished. Also, usability and interactive graphics can be improved and UXON can be extended to aid in UX evaluation of other applications. Regarding "preparing log file", as Compomus generates the log file in text format, the only preparation required is to transcribe this file into comma-separated values (CSV) format, which the UXON receives as input. This is a simple procedure, performed even by non-specialists. In other words, the system does not require any other preparation of the Compomus log file other than transcribing it to CSV format, nor does it require the UX expert to understand the format of the data in the system's database.

In summary, based on the participants' perceptions, UXON was considered a *promising system*, *very helpful*, *useful*, and *easy to use*. Moreover, there are more advantages of using UXON in UX evaluation than disadvantages. Hence, we can conclude that there is an indication that UXON is useful and its use feasible.

6.1.4 Threats to Validity

As any study, this study has some limitations that may have threatened the validity of its results. Thus, these limitations must be considered together with the results. The threats related to this study have been divided into categories, as proposed by [Runeson *et al.*, 2012], and are presented below.

Internal Validity: it is defined as the ability of a new study to repeat the behavior of the current study with the same participants and objects with which it was carried out. One of the main threats to internal validity is communication and information sharing among study participants. To minimize this threat, we sent the questionnaire to the participants by email and the participants were allowed to answer it when and where they wanted. They were asked to answer the questionnaire by themselves, without communication with the other participants. Another threat to be considered is that the study was carried out remotely, thus the participants may have performed other tasks parallel to the study. If we could guarantee that they were exclusively focused on the study, maybe the study results could have been different.

External Validity: this threat is related to the ability to repeat the same behavior with groups different from the one that participated in the study. The main threat in this category refers to the small number of participants. However, considering that they are a representative sample of the population because, at this moment, there are few people who evaluate Compomus UX, we believe that this threat is minimized. Moreover, in evaluations involving specialists, a previous study recommended using groups of 3-5 evaluators [Nielsen, 1992; Barbosa *et al.*, 2021]. Another threat also related to the participants concerns the fact that they were involved in UXON development. Since they were the 'client' of the proposed solution, they were the stakeholders that presented us the problem and provided information so that it was possible to propose the solution.

Construct validity: refers to the relationship between the instruments, the study participants and the theory being proved. For this category, the main threat identified concerns the possibility of misuse UXON functionalities due to the lack of documentation. To minimize this threat, before the participants used UXON, the first author performed a presentation introducing it to P1 and P2 (P3 was not present). There is also the threat of the participants having misunderstood questions contained in the questionnaire. To address this threat, the first author was available to answer questions and support the participants. The questions can also be a threat to the results. Some of them can lead to confirmation bias. We minimized this threat by asking the participants to justify their answers so that they could reflect on the given answers instead of only answering positively or negatively.

Reliability Validity: concerns the extent to which the data collected and analysis performed in the study depend on the researchers who conducted it. Two authors of this paper conducted the analysis of the data provided by the participants in the forms. Thus, the interpretation performed is dependent on them. However, considering that the study involved only three participants and that the answers given were very clear, possibly the results obtained would be similar even if another researcher had analyzed the data provided by the participants. However, the threat of different interpretations and, consequently, different results, is not excluded.

Considering these threats, the study results cannot be generalized and must be understood as preliminary evidence that UXON is useful and feasible to support Compomus UX evaluation.

6.2 Developer Perspective

This section presents an interview carried out with the UXON developer aiming to obtain feedback about the use of (an extract of) HCI-ON in the development of systems to support the solution of HCI-related problems. Section 6.2.1 presents the interview design; Section 6.2.2 addresses its execution and main results; in Section 6.2.3, we briefly discuss the results; and in Section 6.2.4 we present some limitations.

6.2.1 Interview Design

The interview **goal** was to investigate, from the developer's point of view, whether the use of an extract of HCI-ON helps the development of a system to support solving HCI-related problems. Aligned with this goal, we defined two main **questions**:
(Q1) How does the use of an extract of HCI-ON help in the development of a system to support the solution of HCI-related problems?
(Q2) What are the benefits and difficulties of using an extract of HCI-ON in system development to address HCI-related problems?

The **instruments** used in the study consisted of: (i) a consent form; (ii) a form to characterize the participant profile; and (iii) a questionnaire for the interviewer to follow during the interview. The forms were prepared in Google Forms.

In the interview questionnaire Q1 and Q2 were detailed in more specific questions to be answered. They are listed bellow.

- Q1.1. How did you use the HCI-ON extract to develop UXON?
- Q1.2. In which stages of UXON development (analysis, design,…) was the ontology most useful? Why?
- Q1.3. In which stages did the use of ontology not help? Why?
- Q1.4. Do you consider that the HCI-ON extract helped you to have a better understanding of the domain addressed in the developed application (UXON)?

- Q1.5. Do you consider that the HCI-ON extract used in the development of UXON was able to cover the HCI domain treated in the application?
- Q1.6. How did the semantics provided by the conceptualization (from the extract) of HCI-ON (e.g., concepts and their descriptions/meanings, relationships between concepts) help in the development of UXON? Why?

- Q2.1. What benefits have you noticed when using the HCI-ON extract in UXON development?
- Q2.2. What difficulties did you face when using the HCI-ON extract?
- Q2.3. Was this the first time you developed an ontology-based system? Briefly describe your experience.
- Q2.4. Would you use ontologies again to develop another system? Why?

The adopted **procedure** consisted of a face-to-face approach and a semi-structured interview. In the face-to-face approach, an interviewer asks the questions in the presence of the respondent and also completes the questionnaire [Robson and McCartan, 2016]. In the semi-structured interview, the interviewer has an interview guide that serves as a checklist of topics to be covered and the order of the questions. Based on the flow of the interview, the order can be substantially modified and additional unplanned questions can be asked to follow up on what the interviewee says [Robson and McCartan, 2016]. The **participant** was the UXON developer.

6.2.2 Interview Execution and Results

The interviewee was the UXON developer who has 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.

During the interview, the interviewer followed the questionnaire. One question was added during the interview. With the consent of the interviewee, the interview was recorded.

After presenting the interview goal, the interviewer started the interview following the questionnaire. During the interview, the interviewer changed the order of some questions, rephrased some questions, presented examples and interacted with the interviewee to improve her understanding and collecting feedback.

Next, we summarized the main results obtained from the participant answers and comments.

When asked about the use of (an extract of) HCI-ON and if it helped in the development of UXON, the participant reported that she used the ontology (i.e., the HCI-ON extract) to create the conceptual model of UXON and understand *ontoUXON* (Q1.1). According to her, the ontology was more helpful at the Analysis stage, supporting the understanding of the domain (concepts and relationships) for requirements gathering, thinking about and elaborating the requirements, and the things that the system should display (Q1.2). On the other hand, she said that the ontology was not much useful in the Design stage, specifically in the architectural design, e.g., in how to organize the components. She reported that although the ontology helped in the Implementation stage, she had difficulties with the adopted technology and did not have time to study it (Q1.3). She stated that the ontology helped better understand the domain (Q1.4-5). She said that the semantics provided by the ontology helped in the development process (for example, it helped to create the triplestore, assign semantics to concepts and relationships, and create of SPARQLs queries) (Q1.6). Concerning the benefits of using HCI-ON, she cited as the main benefit its support to understanding the domain and added that this considerably reduced the learning curve when compared to a non-ontology-based system. In her words, in non-ontology based development it would take more time and effort to understand the domain (Q2.1). Regarding the difficulties, she said that she did not have difficulties related to ontologies and their manipulation, but to the use of the technologies necessary to implement them (Q2.2). She declared that this was the first time she developed an ontology-based system (Q2.3) and that, based on this experience, she would use ontologies to develop other systems (Q2.4). She briefly explained her experience in developing the UXON as positive and reported that while she found it interesting and would use ontologies again, in her current job, the work is focused on non-ontology-based systems. She added that she would certainly use the ODD approach (domain understanding in development time) to generate the conceptual model. Regarding the OBA approach, she reported that she perceived a lack of available knowledge. Therefore, she said that she would probably not use the OBA approach in future developments.

6.2.3 Discussion

In this section, we present a discussion about the results presented in the previous section in terms of the two questions defined on the interview design (Section 6.2.1.

Regarding Q1, the results from the interview indicated that the use of an extract of HCI-ON helped in the development of an application to support the solution of HCI-related problems. According to the UXON developer, the HCI-ON extract provided great support to the Analysis stage of UXON development. Furthermore, HCI-ON extract helped to gain a better understanding and coverage of the HCI domain addressed in the application, and its semantics certainly helped in the UXON's development. As a drawback, the participant stressed that there was a lack of support in the Design and Implementation stage. As for the Implementation, the limitation was related to the used technologies instead of the ontology.

Concerning Q2, the developer feedback indicated that the main benefits of using an extract of HCI-ON are the ease of understanding the domain and shortening the learning curve when compared to non-ontology-based software development. Furthermore, the developer suggested that the ODD approach may be more suitable for novices in ontology-oriented software development or with little experience in ontologies, while OBA application may require more expertise. As reported by the participant, her greatest difficulty was not in the use of the HCI-ON extract itself, but in the used technologies. As she reported, this difficulty may be due to lack of knowledge and time to study. Moreover, the use of operational ontology in software coding is already a challenge, especially for non-experienced people (which was the case of the participant). When this is combined with the use of technology not known for the developer, we believe that these difficulties can be increased.

The overall results of the interview indicated that the use of an extract of HCI-ON helped in UXON development (from its developer's point of view). Despite its greater contribution had been in the development time (ODD approach), it was not possible to properly evaluate how HCI-ON contributed in the run-time because the developer had difficulties to use the adopted technologies (e.g., Flask, Python), which may have prevent her from perceiving the actual impact of using HCI-ON at run-time.

6.2.4 Limitations of the Study

The results discussed in the previous section should be considered, together with some study limitations. The main limitation regards the participation of one of this paper authors in UXON development. The UXON developer carried out UXON development in the context of her undergraduate project, which was supervised by two of this paper authors. This may have influenced the developer perception of using the extract of HCI-ON. Moreover, this may also have an influence on the interviewee answers.

To minimize the influence of the relation between interviewee and interviewer during the interview, the interviewer followed some recommended procedures: she listened more than she spoke; posed questions in a straightforward, clear and non-threatening way; and tried to get interviewee to talk freely and openly. Even so, it is not possible to eliminate biases.

Another limitation concerns the developer profile. She is a beginner in ontology-oriented software development. The fact that she was the only developer of UXON is also a limitation because we could not get feedback from other people. Some limitations inherent in interviews in general also apply to this study. First, interviewing is time-consuming. It can make the interviewee tired, influencing their answers. The interview was very straightforward and lasted 38 minutes. It was recorded, so the interviewer did not need to spend time writing the answers. Second, the participant may misunderstand some questions. To avoid this, the interviewer exemplified some questions and/or redrafted the questions in order to facilitate understanding. Moreover, she changed the order of the questions to better adapt to the flow of the interview. Last, some questions can lead to confirmation bias. In such cases, the interviewer asked the participant to justify her answers.

Considering these limitations, the results are not conclusive and should be considered as preliminary evidence that the use of an extract of HCI-ON helps develop systems to address HCI-related problems.

7 Evaluating the Conceptualization behind UXON

Developing UXON showed us that using networked ontologies to develop a system to support HCI evaluation is feasible and the produced solution – UXON – is useful. Considering the relevance of the conceptualization (i.e., the HCI-ON extract) used to develop UXON and the potential of reusing it to develop other tools or in other applications, we carried out a study with HCI experts to evaluate if its concepts are adequate and understandable by third parties, and can therefore be adopted by other researchers and practitioners to address HCI evaluation problems. The study was approved by The Ethics Committee of the Federal University of Amazonas (UFAM), with registration number CAAE: 76726923.4.0000.5020. This section presents the study: Section 7.1 presents the study design; Section 7.2 addresses its execution and main results; in Section 7.3, we discuss the results; and Section 7.4 concerns the threats to validity.

7.1 Study Design

The study ***goal*** was to verify whether the concepts behind UXON [11] are adequate and understandable by third parties. Following the GQM approach [Basili *et al*., 1994], this goal is formalized as follows:

> *Analyze* the HCI-ON conceptualization used to develop UXON
> *With the purpose of* evaluating its concepts
> *Regarding* adequacy and understandability
> *From the point of view of* HCI experts
> *In the context of* HCI evaluation

To evaluate *adequacy*, we considered the HCI experts' perceptions of how much the HCI-ON's concepts behind UXON are in accordance with their knowledge of the domain. To evaluate *understandability*, we considered the HCI experts' perceptions of how easy they considered understanding the concepts' definitions.

The ***instruments*** used in the study consisted of (i) a *consent form* to participate in the study; (ii) a *characterization form* to capture the participants' profile; (iii) a *document* presenting the definitions (and examples) of the concepts behind UXON (which should be evaluated); and (iv) a *questionnaire* that allowed participants to record their perception about the concepts. The forms were prepared using Google Forms. The instruments used in the study are available in [Costa and Barcellos, 2024a].

The document presenting the concepts to be evaluated includes (i) the description of a real-world HCI evaluation scenario, and (ii) a table containing 19 concepts with their respective descriptions, and examples extracted from the presented scenario. Considering that some people may not be familiar with ontologies, we used a textual document to evaluate the concepts instead of the ontology model and formal description. In this way, the participants would be able to evaluate the concepts regardless of their knowledge of the ontology subject. Figure 21 presents a storyboard illustrating the scenario described in the document. Figure 22 presents a fragment of the table describing the concepts.

The questionnaire included 21 objective questions, whose possible answers are based on the Likert scale. For each of

[11] For simplification, in this section we refer to the HCI-ON concepts used to develop UXON as *the concepts behind UXON*.

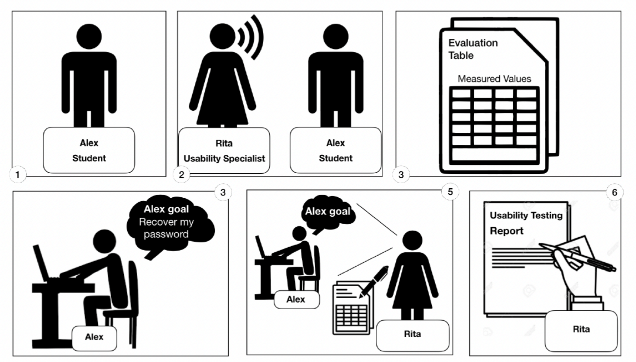
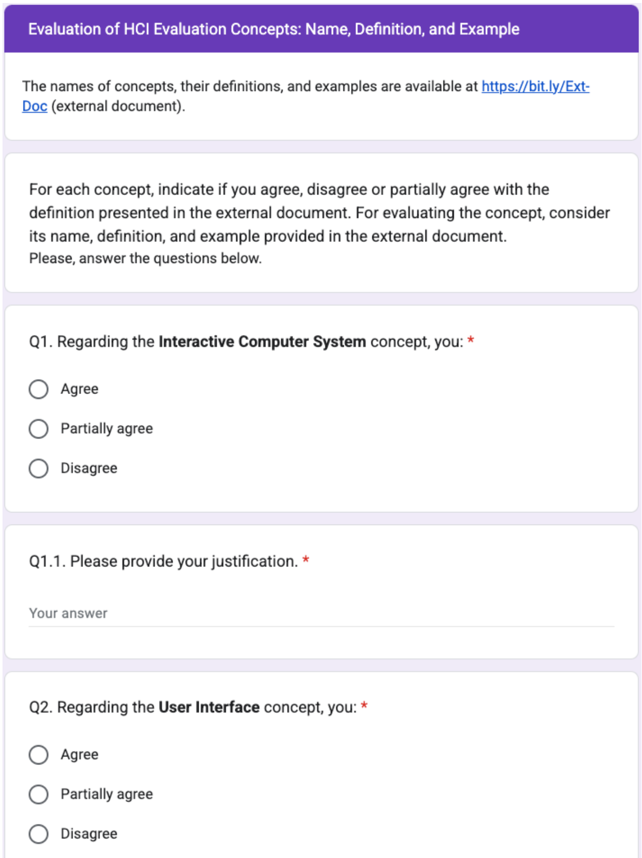


Figure 21. Storyboard illustrating a real-world HCI evaluation scenario.

Concept	Example
Interactive Computer System	
A computer system that combines, hardware and software and has a **User Interface**. It is designed to process, transform, store, display, or transmit information or data by receiving inputs and communicating outputs to **Users**.	The web system
User Interface	
All components (software or hardware) of an **Interactive Computer System** that provide information and controls to enable the **User** to perform specific tasks with the system.	The web system's UI, which involves both software (e.g., the programs that show the login screen to the user) and hardware (e.g., the mouse and the keyboard) components.
User	
A person who interacts or is expected to interact with an **Interactive Computer System**.	Alex
Human-Computer Interaction	
An exchange of information (i.e., communication) between a **User** and an **Interactive Computer System** through the **User Interface**. Both the **User** and **Interactive Computer System** participate in a Humam-Computer Interaction.	When Alex enters an incorrect password in the UI login of the web system, the system displays a message informing him that the password is incorrect and that he has only two more attempts.

Figure 22. Fragment of the table presenting concepts.


Evaluation of HCI Evaluation Concepts: Name, Definition, and Example

The names of concepts, their definitions, and examples are available at https://bit.ly/Ext-Doc (external document).

For each concept, indicate if you agree, disagree or partially agree with the definition presented in the external document. For evaluating the concept, consider its name, definition, and example provided in the external document.
Please, answer the questions below.

Q1. Regarding the **Interactive Computer System** concept, you: *

- Agree
- Partially agree
- Disagree

Q1.1. Please provide your justification. *

Your answer

Q2. Regarding the **User Interface** concept, you: *

- Agree
- Partially agree
- Disagree

Figure 23. Fragment of the questionnaire.

them, the participants were asked to justify their answers. There was also a subjective question in which the participants could provide additional comments and suggestions. A fragment of the questionnaire is presented in Figure 23. The complete form is available in [Costa and Barcellos, 2024a].

The ***procedure*** adopted in the study involved inviting participants via email. The participants were selected from the HCI community by convenience, considering the authors' network. The invitation email included (i) a link to the document presenting the concepts, along with their respective definitions and examples extracted from the described HCI evaluation scenario, and (ii) a link to the questionnaire, with instructions to answer it. After the participants answered the questionnaire, we organized the data in a spreadsheet and, thus, we analyzed it according to the study goal. The collected data is available at [Costa and Barcellos, 2024a].

The ***participants*** were seven members of the Brazilian HCI community, with intermediate to advanced levels of theoretical knowledge and practical experience in the field. Consequently, these HCI experts understand what an HCI evaluation entails, how it operates, what it involves, the artifacts used, and the outcomes produced. This expertise enables them to compare the concepts behind UXON with their knowledge of the domain.

7.2 Study Execution and Results

We invited 10 members of the HCI community to participate in the study. Seven out of them accepted our invitation and participated in the study. Here, they are designated as P1 to P7. Concerning their profile, all participants possess an academic background in Computer Science. P1, P2, and P3 hold Ph.D. degrees and reported having a high level of both theoretical knowledge and practical experience in HCI evaluation. Participants P4, P5, P6, and P7 indicated an intermediate level of both theoretical knowledge and practical experience in HCI evaluation. P4 has a Ph.D. degree, P5 is a doctorate student, P6 is an undergraduate student and P7 is doing a specialization course.

The participants had up to two weeks to access the materials, complete the questionnaire, and submit their responses. After that, we organized and analyzed data, deriving the key results and conclusions from the participants' answers and feedback. Next, we summarize the main results. We organize them into two topics: the first one refers to the participants' perception of each concept individually (we name it *specific perspective*), while the second concerns the general perception of the concepts as a whole (we name it *general perspective*). In the text, we present some comments made by the participants to justify their answers. The comments are not exhaustive. The complete data collection is available at [Costa and Barcellos, 2024a].

Specific Perspective

Figure 24 illustrates the evaluated concepts and the corresponding responses, categorized as agree, partially agree, and disagree.

Of the 19 concepts analyzed in the study, all participants fully agreed with seven of them: ***HCI Evaluation***, ***HCI Evaluation Report***, ***Measure Unit***, ***Scale***, ***Measurement***, ***Measurement Formula***, and ***Measured Value***. The justifications given by the participants include: the concept is well-defined,

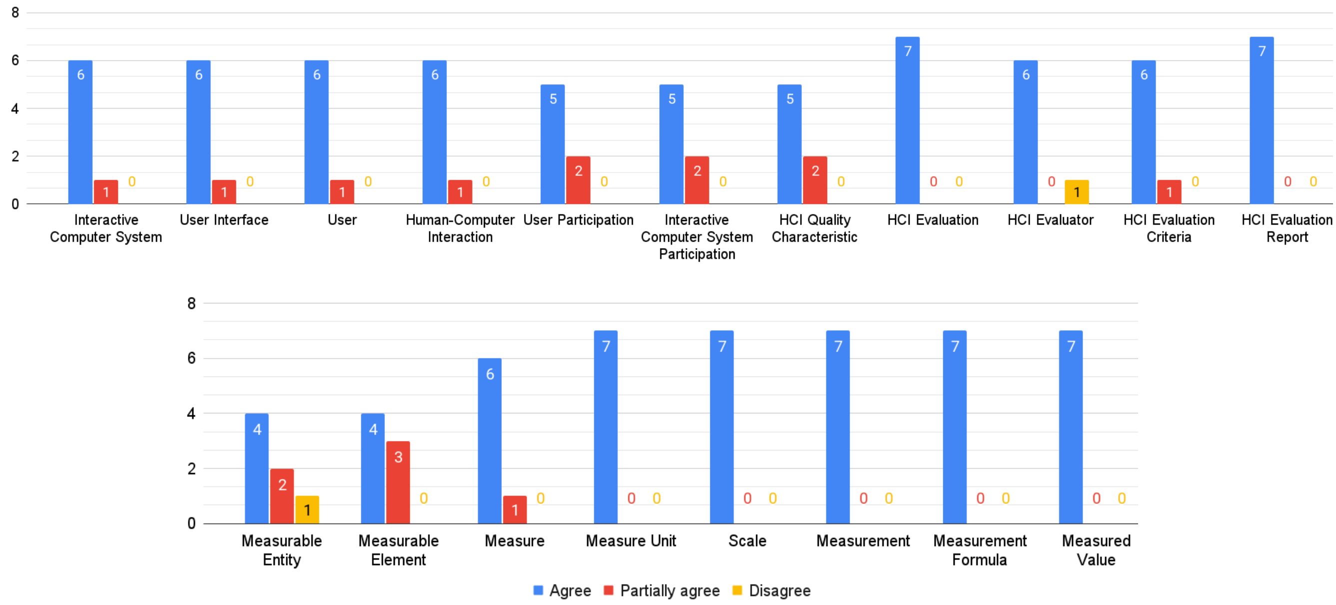


Figure 24. Participants' perception of each concept behind UXON.

with the example aiding understanding; the definition effectively explains the process behind the concept; and the concept is straightforward to grasp. Concerning *Measurement*, P1 commented that the concept is initially difficult to understand and requires multiple readings but the example provides clarification. Conversely, P6 said that the concept is simple and straightforward and stated that the measurement-related concepts are intuitive and easy to understand. P7 highlighted that the names are self-explanatory and the explanation effectively provides important context.

Six participants (85.7%) fully agreed and one (14.3%) partially agreed with the following six concepts: ***Interactive Computer System***, ***User Interface***, ***User***, ***Human-Computer Interaction***, ***HCI Evaluation Criteria***, and ***Measure***. Regarding *Interactive Computer System*, P6 justified agreeing with the concept as it "*restricts the boundaries of an Interactive Computer System to something that combines hardware, software, UI, as well as different data manipulation capabilities. From these conceptual limitations, I know exactly which systems fall within this scope and which do not*". On the other hand, P7, who partially agreed, believes the definition seems to be more focused on internal computer processes, without emphasizing user interaction.

About *User Interface*, P7 highlighted that the concept was clear and concise. In contrast, P6 partially agreed that it combines software and hardware for user interaction but, according to P6, in the IoT (Internet of Things) context, some systems may display a UI only through hardware.

Concerning *User*, most participants agreed that the concept is correct for systems designed for human users. P6 partially agreed because the concept does not consider non-human users. As for *Human-Computer Interaction*, P7, who partially agreed, missed a better explanation of the interaction process, including the flow of input and output, which is crucial for understanding HCI. P7 also partially agreed with *HCI Evaluation Criteria* and said that it is important to specify that these criteria are non-functional requirements. As for *Measure*, P3 partially agreed with the presented example because, for P3, the example should be the collected value.

Five participants (71.4%) fully agreed and two (28.6%) partially agreed with the following three concepts: ***User Participation***, ***Interactive Computer System Participation***, and ***HCI Quality Characteristic***. Some of the reasons for a partial agreement were: *User Participation* should include a definition of 'user action' because user participation involves user actions (P6); *Interactive Computer System Participation* should consider that systems sometimes initiate interaction, thus it should be the event in which the Interactive Computer System initiates or participates in a Human-Computer Interaction (P2); the notion of intentionality is unnecessary in *Interactive Computer System Participation* (P2); *HCI Quality Characteristic* needs additional examples as it can be challenging to abstract quality criteria in HCI beyond usability and user experience (P6); *HCI Quality Characteristic* should consider the emotions, states, and feelings the system evokes in users (P2).

Four participants (57.1%) agreed and three (28.6%) partially agreed with the ***Measurable Element*** concept. P3 argued that *Measurable Element* should have the definition presented to *Measure*. P6 questioned the distinction between this concept and *HCI Quality Characteristic*, noting that they appear identical. P7 missed a more practical clarification for the concept because it relies on another concept.

Finally, one participant (14.3%) disagreed with the ***HCI Evaluator*** and ***Measurable Entity*** concepts. Regarding *HCI Evaluator*, P7 disagreed because, in their view, the concept suggests a professional specialized in the field of HCI, rather than someone responsible for a single HCI evaluation. As for *Measurable Entity*, P3, who also encountered difficulties with the definitions of *Measurable Element* and *Measure*, pointed out that a system can be measured in various ways, but from a human-computer interaction perspective, the focus should be on measuring user actions or interactions, such as usability. P7 partially agreed and stated that not all measurable items qualify as entities. P6, who also partially agreed, questioned if an Interactive Computer System can be distinguished from a Measurable Entity.

General Perspective

While the previous questions focused on each concept individually, the last questions of the questionnaire aimed at the general perception of the participants about the concepts' *understandability* and *adequacy*.

Concerning *understandability*, two participants (28.6%) found the concepts *very easy* to understand and five participants (71.4%) found them *easy* to understand. Those who found them very easy noted that, except for *Measurement*, the other concepts were straightforward (P1); and that the use of clear terms and helpful examples facilitated understanding (P2). Participants who found the concepts easy to understand commented that the concepts were generally well-represented and clarified by the examples (P4, P5), and understanding the concepts was generally easy, with difficulties arising only with some measurement-related concepts (P3). P6 noted that while there is a lack of formal definitions or illustrations about HCI evaluation, the presented concepts define relevant aspects in the domain. P7, with significant experience in the field, found the concepts easy but noted that they could be improved for newcomers.

As for *adequacy*, three participants (42.9%) found the concepts *very adequate* while four participants (57.1%) considered them *adequate*. P3 stated that the concepts effectively characterize HCI evaluation; P6 said that the concepts cover the basics and common knowledge expected from experts in usability and user experience evaluations; P7 remarked that the concepts fulfill their intended explanation, though some are very concise.

The participants were also asked to provide general comments they found relevant. Two participants (P3 and P6) answered this question and pointed out that adding other examples to the concepts would be beneficial. P6 highlighted that in some cases, the same example is presented for different concepts (i.e., it is an instance of different concepts) – e.g., usability is an example of *HCI Quality Characteristic* and *Measurable Element*. Thus, other examples could help the understanding of how the concepts differ from each other.

7.3 Discussion

By analyzing the participants' perspective of each concept, we observe a predominance of full agreement in all concepts. Although some participants partially agreed with some concepts and one participant disagreed with two concepts, the agreement level is high. This indicates that the concepts are *adequate.*

By looking at the answers the participants provided when asked about the concepts' adequacy, all participants considered the concepts adequate or very adequate, which reinforces the conclusion obtained from the specific perspective. Moreover, concerning how difficult was to understand the concepts, all the participants found that it was very easy or easy, which indicates that the concepts are *understandable*.

These results suggest that the concepts behind UXON properly describe relevant aspects of HCI evaluation and can be easily understood. The study results also contributed to improving the definition of the networked ontologies' concepts and increasing their soundness. Therefore, we believe that the conceptualization can be used by other people as the basis for solving problems related to HCI evaluation, such as developing tools to support HCI evaluation (similar to UXON), supporting communication, assigning semantics to data, and aiding in interoperability tasks, among others.

When evaluating the concepts, the participants provided some interesting comments. In the following, we discuss some aspects of the evaluation of the concepts from the *specific perspective*. To structure the discussion, we organized the concepts into two groups: HCI, comprising the concepts directly related to this domain, and Measurement, comprising concepts required to quantify aspects of an HCI evaluation.

Concerning the concepts directly related to **HCI**, there was full agreement in *HCI Evaluation* and *HCI Evaluation Report*. These concepts represent fundamental aspects of an HCI evaluation: the evaluation process itself and the resulting evaluation report. Given that the study participants possess intermediate to high levels of theoretical knowledge of and practical experience with the subject, we could expect that these concepts would align with their perceptions and be quickly grasped by them. One or two participants partially agreed with *Interactive Computer System*, *User Interface*, *User*, *Human-Computer Interaction*, *HCI Evaluation Criteria*, *User Participation*, *Interactive Computer System Participation*, and *HCI Quality Characteristic*. Next, we discuss some of the participants' comments related to each concept.

Interactive Computer System: P7 commented that the definition refers to the computer system and lacks emphasis on human-computer interaction. Since interactive computer systems are designed to interact with humans, human-computer interaction is indeed an important aspect, as pointed out by P7, and could be clearer in the *Interactive Computer System* definition. We must point out that although the *Interactive Computer System* definition does not mention explicitly human-computer interaction, the *Human-Computer Interaction* definition connects the two concepts.

User Interface: P6 argued that, while the current definition of *User Interface* suggests that it is composed of hardware and software, in IoT systems, the user interface may be composed solely of hardware. We understand P6's point. However, the proposed definition of *User Interface* ("*all components (software or hardware) of an Interactive Computer System that provides information and controls to enable the User to perform specific tasks with the system*") does not exclude these cases, because user interface can be made up of software *or* hardware. We believe that the participant did not notice the "or" connector and understood it as "and".

User: P7 raised the possibility of non-human users, particularly in AI-related contexts. This feedback highlights situations with machine-to-machine interactions. Currently, the conceptualization is primarily human-centered, focusing on users as individuals with specific intentions and objectives. This approach overlooks the increasing significance of non-human interactions, which are becoming more relevant across different contexts. There is a possibility of extending the conceptualization to address system-to-system interactions, which fundamentally differ from human-computer interactions.

Human-Computer Interaction: P7 commented that the definition should more clearly describe the interaction process between the user and the system, including the flow of input and output information. This understanding is indeed important. In the study, we included only the concepts from the HCI-ON fragment used to develop UXON, which is the focus of this paper (the participants were advised that they would evaluate a limited set of concepts). HCI-ON contains many other concepts that relate to the concepts considered in the study. Thus, the explanation required by P7 is presented in other concepts. In HCI-ON the human-computer interaction is approached comprehensively, addressing different interaction paradigms.

User Participation: P6 emphasized the need to define 'user action', as user participation consists of actions the user performs when interacting with the system. P6's point is correct and, once more, although this issue is treated in HCI-ON, the concepts that address it directly are not in the HCI-ON fragment used to develop UXON. HCI-ON addresses the user participation in human-computer interactions in terms of specific actions, such as user-initiated actions, both intentional and unintentional actions, interpretations actions, as well as varying levels of granularity, which can range from complex (composed of multiple actions) to atomic.

Interactive Computer System Participation: P2 pointed out that in new interaction paradigms, the system can initiate an interaction (e.g., through notifications) and said that it would not be necessary to inform that the system participation is unintentional since systems lack human-like intentions. We agree with P2's observations. Concerning the system initiating an interaction, again, this is not clear in the set of concepts considered in the study but it is approached in other parts of HCI-ON, which addresses several types of interaction, initiated (intentionally or not) by the user or by the system.

HCI Quality Characteristic: P2 pointed out the need to consider the emotional aspects the system can cause in the users. This is indeed a good observation. Currently, although the concept name refers to "HCI characteristic", its definition focuses on the qualities of the interactive computer system. We recognize that the effects of human-computer interaction on users represent qualities that are intrinsic to human beings (such as anger, fear, frustration, etc.) and are not properly represented in the proposed concept. We believe that we could extend the conceptualization by defining two types of HCI Quality Characteristics, one focused on the system, and the other focusing on the user.

HCI Evaluation Criteria: P7 noticed that such criteria are non-functional requirements, defining capabilities for the system. P7 observation is correct. The proposed definition refers to HCI Evaluation Criteria as requirements, and it should be more specific by indicating that they are non-functional requirements.

HCI Evaluator: P7 argued that the concept may indicate the need for a professional specialized in HCI. We believe that the participant understood the concept as a job, specialization, or function. We must clarify that the concept refers to the *role* played by an individual organization (regardless of their job, specialization, or function) that is responsible for an HCI evaluation. The name was defined to express that in an HCI evaluation, the person or organization responsible for it plays the role of HCI evaluator.

Regarding the concepts related to **Measurement**, there was a full agreement with *Measure Unit*, *Scale, Measurement*, *Measurement Formula*, and *Measured Value*. Although the measurement domain involves some concepts that may be confusing, according to the participants' perceptions, the ones aforementioned seem to be clear. However, some participants raised questions about the other three concepts: *Measure*, *Measurable Entity*, and *Measurable Element*. Next, we discuss some comments related to these concepts.

Measurable Entity: P7 argued that not all measurable items qualify as entities. We agree with P7. For example, properties are also measurable and they are addressed in the *Measurable Element* concept. The definition of *Measurable Entity* as "*anything that can be measured*" needs adjustment. P6 asked for a differentiation between an Interactive Computer System and a Measurable Entity. *Interactive Computer System* is a subtype (i.e., a specialization) of *Measurable Entity* (as shown in Figure 2). Given that *Interactive Computer System* is a subtype of *Measurable Entity*, a particular web system, which is an instance of *Interactive Computer System* is also an instance of *Measurable Entity* and, as such, it is an entity that can be measured. Given that in the document used in the study we decided to focus on the concepts and not explore all their relationships, this relation is not explicit in the definitions or examples provided, which may have led P6 to have that doubt.

Measurable Element: P6 also asked about the distinction between *Measurable Element* and *HCI Quality Characteristic*, indicating that the examples suggest that the two concepts overlap. Similar to the explanation presented above, *HCI Quality Characteristic* is a subtype (i.e., a specialization) of *Measurable Element* (as shown in Figure 2). For example, given that *HCI Quality Characteristic* is a subtype of *Measurable Element*, usability, which is an instance of *HCI Quality Characteristic*, is also an instance of *Measurable Element* and, as such, is a property that can be measured. We believe that this doubt was raised because we did not explain these relations in the definitions or examples provided to the participants.

Measure: P3 questioned the presented examples and argued that measure should refer to the value itself. We understand P3's doubt. The many inconsistent terminologies used in the measurement domain cause semantic conflicts and lead to doubts like the ones presented by P3 in the study. For instance, in the literature, sometimes the terms measure and metrics are used with the same meaning. Other times, measure is used to designate the value collected for a metric (which we call measured value). Considering the terminology diversity, we adopted one consistent with standards devoted to measurement (e.g., ISO/IEC/IEEE [2017]; ISO/IEC [2007]; McGarry *et al.* [2002]). We believe that P3's knowledge of measurement-related concepts is probably rooted in a terminology different from the one we used, which certainly contributed to P3 having difficulties and questions related to *Measure*, *Measurable Entity*, and *Measurable Element*, which are measurement core concepts.

Analyzing the comments made by the participants, we notice that some of them indicate opportunities for us to extend the concepts' definitions (e.g., to consider non-human users and address user feelings caused by human-computer interaction). Others suggest that some concepts need further clarification (e.g., make explicit that *HCI Evaluation Criteria* are non-functional requirements). One comment identified the need to correct the *Measurable Entity* definition. In some cases, we observed that our decision to focus on the concepts and not explore their relationships hindered the participants' understanding of some concepts (e.g., *Interactive Computer System* and *Measurable Entity*, *HCI Quality Characteristic* and *Measurable Element*).

Moreover, as we provided the participants with a limited set of concepts (the ones directly used to develop UXON), some aspects related to HCI evaluation were not addressed and the lack of them to provide a more comprehensive view of the subject was observed by some participants. We must emphasize that, in this study, we did not evaluate the conceptualization comprehensiveness. As we selected the HCI-ON fragment used to develop UXON, it is limited to that scope, and, thus, does not cover all aspects related to HCI evaluation. The need to refer to concepts beyond the ones addressed in the HCI-ON fragment used to develop the tool may be an indication that even though one can extract the HCI-ON fragment containing the concepts to be directly used (e.g., to develop a tool), it may be beneficial to understand some related-concepts to get a better understanding of the used conceptualization.

Except for one comment, which indicated the need to correct one definition, the other comments do not indicate any critical problem in the conceptualization behind UXON. This conclusion is corroborated by the high level of adequacy and understandability resulting from the participants' perceptions. Based on the participants' main comments, we adjusted the definition of some concepts. The table of concepts, containing the concepts' definitions, examples, and the description of the HCI evaluation scenario used to exemplify the concepts are presented in Appendix A.

7.4 Threats to Validity

In this section, we discuss some limitations that may affect the study's validity and should be considered with the results. Like in Section 6.1.4, we categorize them according to [Runeson *et al*., 2012].

Concerning *Internal Validity*, in this study, we also faced the threats we experienced in UXON evaluation, i.e., the potential for communication among participants (we addressed it by emailing the study material to participants individually instead of in a single thread, who were instructed to respond without interacting with other participants) and the risk of the participants performing other tasks during the study. An additional threat is the time the participants had to answer the questionnaire. The short time may have led some participants to provide less feedback than they would have provided if they had had more time.

Regarding *External Validity*, a primary concern is the limited number of participants. Although the sample size is limited (seven individuals), it is in accordance with previous studies [Nielsen, 1992; Barbosa *et al*., 2021] that recommend the participation of 3-5 individuals in evaluations involving specialists. Another threat is the predominance of participants from the Academy. To address this threat, the study participants have theoretical knowledge and practical experience with the subject. An additional threat to be considered is the fact that two of the HCI experts also participated in UXON evaluation. Given that in UXON evaluation they did not evaluate the concepts and the material used in this study was totally new for them, we believe that the threat is minimized. Even so, it is necessary to consider that they may have been influenced by the experience and knowledge gained during the UXON evaluation.

As for *Construct Validity*, an important threat is the potential for misinterpretation of the document containing the concepts' definitions. To mitigate this threat, one researcher reviewed the document. Moreover, we described a real-world HCI evaluation scenario encompassing all relevant concepts and provided illustrative examples. We also defined the concepts in an objective manner. However, while objectiveness may help avoid misinterpretation, it can lead to doubts due to the lack of details. Furthermore, the formulation of the questions may pose a risk to the results, as some may inadvertently lead to confirmation bias. We addressed this concern by requiring participants to justify their responses, encouraging them to engage in reflective thinking about their answers. Another threat that should be considered regards the decision to use a textual document to evaluate the conceptualization instead of the HCI-ON fragment conceptual model and formal description. As explained earlier, we decided to do that to enable people unfamiliar with ontologies to evaluate the concepts. On one hand, this simplifies the presentation of the concepts and favors the evaluation by different HCI experts. On the other hand, the relationships between concepts are under-explored, which constrains the present conceptualization and can impact the results. As discussed in the previous section, comments made by some participants revealed the need to make the existing relationships more explicit. The use of a limited set of concepts related to HCI evaluation instead of a comprehensive conceptualization of that domain is also a threat. The lack of some concepts that could help clarify others may have affected the participants' understanding.

Lastly, concerning *Reliability Validity*, we cannot fully eliminate the researchers' bias on the results. Thus, the possibility of varying interpretations and results cannot be entirely dismissed. Even so, aiming to minimize this threat, two authors were responsible for independently analyzing the data provided by the participants. After that, another author critically reviewed the produced results.

Given these threats and limitations, the study's results should be regarded as preliminary evidence of the adequacy and understandability of the HCI-ON conceptualization behind UXON.

8 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 [Costa *et al.*, 2021] 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 [2012, 2013], Elyusufi *et al.* [2014], and Mezhoudi and Vanderdonckt [2015], which propose ontologies including concepts related to HCI evaluation methods. The proposal by Negru and Buraga [2012, 2013] includes Usability Test concept as a way to evaluate HCI, while the ones by Elyusufi *et al.* [2014] and Mezhoudi and Vanderdonckt [2015] address some concepts related to the 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: [Arango-López *et al.*, 2018] addresses metrics in the context of pervasive experience and [Bakaev *et al.*, 2019] structures some metrics related to Web user interface. Different from *HCI-ON*, 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 *HCI-ON* 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, *HCI-ON* provides a conceptual framework that allows using any metric to support HCI evaluation, while [Arango-López *et al.*, 2018] and [Bakaev *et al.*, 2019] consider only some specific metrics for particular HCI sub-domains.

From the cited works, only two use the proposed ontology in systems development ([Elyusufi *et al.*, 2014] and [Bakaev *et al.*, 2019]) and only one of them uses it in the HCI evaluation context. In [Bakaev *et al.*, 2019], 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.

9 Final Considerations and Future Work

UX is a key quality attribute of interactive systems, with subjective characteristics such as the feelings and emotions of the users [Rivero and Conte, 2017; Barbosa *et al.*, 2021; Hassan and Galal-Edeen, 2017]. 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 [Feilmayr and Wöß, 2016]. Although they have been used in several domains, their use in HCI in general, and in HCI evaluation in particular, should be further explored [Costa *et al.*, 2021]. With this work, we give a step in this direction and shine a light on opportunities for using 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.

Before UXON was available, UX experts needed to handle log data with very little support. As a result, the effort and time spent on manually getting and structuring data regarding many users recorded in log files were very high. UXON contributed 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 was possible to analyze and reflect on the UX provided by *Compomus*. In addition, the graphs and tables generated by the tool made 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.

We conducted a study and collected feedback from the UXON developer and three UX experts who used it. The results showed that using networked ontologies to develop a tool to support UX evaluation is feasible and valuable. The use of the 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's 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.

Considering the relevance of the conceptualization (i.e., the HCI-ON extract) used to develop UXON and the potential of reusing it in other HCI evaluation solutions, we carried out a new study to evaluate its concepts. The study showed that the conceptualization is adequate and understandable, having the potential to be used by other people to address

HCI evaluation problems. We created a document containing a real-world HCI evaluation scenario, the definition of 19 concepts related to HCI evaluation, plus examples extracted from the evaluation scenario. The document is more user-friendly for people not familiar with ontologies and can help them understand concepts related to HCI evaluation.

This work has some limitations that must be considered together with the results. We 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 was 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 evaluating 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 have so far. We also plan to extend UXON to encompass UX evaluation of other applications that record data in interaction logs.

Declarations

Acknowledgements

We thank our dear friend Ricardo Falbo, who participated in the beginning of this work, when we started to develop the ontologies, and unfortunately passed away during its development. He will be always alive through his legacy and within us.

Funding

This research is supported by the Espírito Santo Research and Innovation Support Foundation - FAPES (Processes 2023-5L1FC, 2021-GL60J, 2022-NGKM5, 2022-NLTT9 and T.O. 1022/2022). Also financed in part by the CAPES - Finance Code 001, and partially supported by FAPEAM - through the POSGRAD project and 062.00150/2020 process, and CNPq processes 314174/2020-6.

Authors' Contributions

Simone D. Costa. Conceptualization, Methodology, Software, Writing-Original draft. *Carolina F. Manso*: Software. *Leonardo C. Marques*: Conceptualization, Writing-Original draft. *Bruno F. Gadelha*: Conceptualization, Writing-Review & Editing. *Tayana U. Conte*: Conceptualization, Writing-Review & Editing. *Monalessa P. Barcellos*. Conceptualization, Methodology, Writing-Review & Editing, Supervision.

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

- HCI-ON: `https://dev.nemo.inf.ufes.br/hcion/`
- ontoUXON: `https://dev.nemo.inf.ufes.br/hcion/ontoUXON.owl#`
- UXON: `https://dev.nemo.inf.ufes.br/uxon/`
- UXON Evaluation Materials: `https://doi.org/10.6084/m9.figshare.25452535`
- UXON's source code: `https://github.com/cfmanso/UXON-final`
- UXON's video: `https://bit.ly/UXON_overview`

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A The Concepts behind UXON

This appendix presents the concepts used to develop UXON. Section A.1 describes an HCI evaluation scenario. Section A.2presents the concepts, their definitions, and examples extracted from the scenario.

A.1 HCI Evaluation Scenario

Rita is a usability specialist and is responsible for conducting the evaluation of the user interface (UI) of the web system used by the students of a university. Today she needs to evaluate the login UI. Alex is a student and will participate in the evaluation (Figure 25, 1st picture).

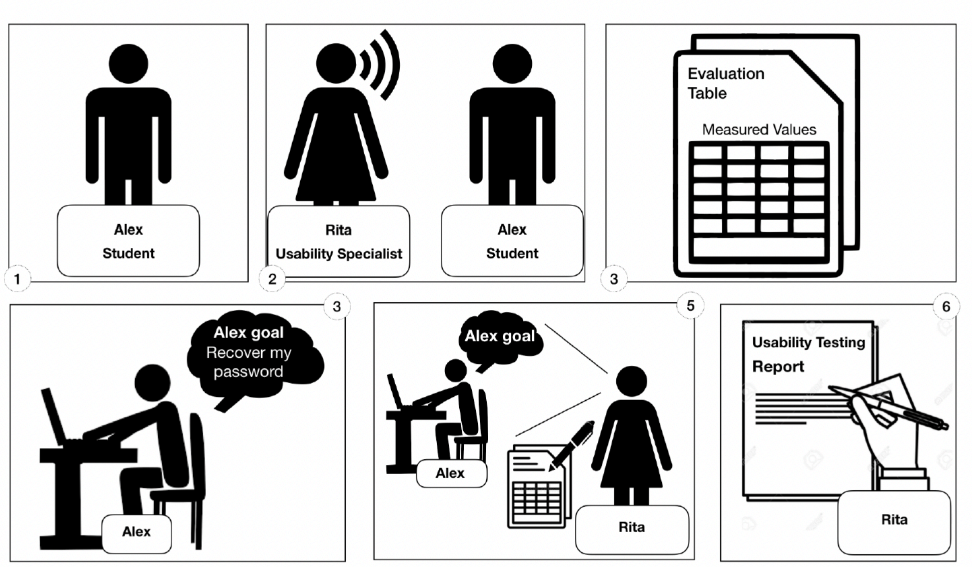

Figure 25. HCI Evaluation Scenario.

Rita will adopt Usability Testing as the evaluation method. In this method, users interact with the system to evaluate its usability. Rita informs Alex that he must use the system and perform the password recovery task (2nd picture). Rita observes Alex interacting with the system and, simultaneously, makes measurements to evaluate its usability. Rita defines that the usability will be evaluated considering the following: (i) the time spent to recover a password the first time the user used the system versus; (ii) the second time; (iii) the number of wrong clicks or touches; and (iv) the number of requests for help. It is expected that: the time to perform the password recovery task does not exceed two minutes on the first attempt to use the system and one minute on the second one, there are no requests for help and no more than two wrong clicks or touches are given. Rita establishes that the usability degree will be given by the sum of these values. Ideally, the result should not exceed five. Otherwise, it indicates that one or more criteria were not met.

To perform the evaluation, Rita uses a table to record the values measured during the evaluation (3rd picture), so that they can then be compared with the corresponding expected values.

Alex interacts with the system (to recover the password) (4th picture). Meanwhile, Rita observes him interacting, performs measurements, and records the measured values in the table (5th picture). Alex asked for help three times, made two wrong clicks, and took three minutes to recover the password on the first use and one and a half on the second use.

After Alex completes the task, Rita elaborates a report containing the evaluation results, informing the differences between the expected as well as additional comments she considers relevant to record (6th picture).

A.2 Concepts

Table 1 presents some concepts related to HCI evaluation (the ones directly used in UXON development). For each concept, we present its definition and we use the scenario described before to exemplify it.

Table 1. Concepts and Examples.

Concept	Example
Interactive Computer System	
A computer system that combines, hardware and software and has a **User Interface**. It is designed to process, transform, store, display, or transmit information or data by receiving inputs from and communicating outputs to **Users**.	The web system

Table 1 – *Continued from previous page*

Concept	Example
User Interface	
All components (software or hardware) of an **Interactive Computer System** that provide information and controls to enable the **User** to perform specific tasks with the system.	The web system's UI, which involves both software (e.g., the programs that show the login screen to the user) and hardware (e.g., the mouse and the keyboard) components.
User	
A person who interacts or is expected to interact with an **Interactive Computer System**.	Alex
Human-Computer Interaction	
An exchange of information (i.e., communication) between a **User** and an **Interactive Computer System** through the **User Interface**. Both the **User** and **Interactive Computer System** participate in a Humam-Computer Interaction.	When Alex enters an incorrect password in the UI login of the web system, the system displays a message informing him that the password is incorrect and that he has only two more attempts.
User Participation	
The action in which the **User** participates in a **Human-Computer Interaction**. User Participation is an intentional event (i.e., it is caused by an intention of that **User**). The User Participation can initiate a **Human-Computer Interaction** or occur in response to an **Interactive Computer System Participation**.	Alex entering with his password in the UI login of the web system (in this case, the user participation initiates the human-computer interaction)
Interactive Computer System Participation	
The event in which the **Interactive Computer System** participates in a **Human-Computer Interaction**. The Interactive Computer System Participation can initiate a **Human-Computer Interaction** or occur in response to a **User Participation**.	When the system shows a message informing Alex that he provided an incorrect password and has only two other attempts (in this case, the system participation is a response to the user participation in the human-computer interaction).
HCI Quality Characteristic	
Characteristics of an **Interactive Computer System**, encompassing both software (e.g., usability) and hardware (e.g., screen size of a smartwatch) components. They can refer to the entire **Interactive Computer System** or specific parts (e.g., the **User Interface** or an input/output device) *Note: When an HCI Quality Characteristic is quantifiable, it is a* ***Measurable Element*** *(i.e., property) of the* ***Interactive Computer System***.	Usability
HCI Evaluation	
Action performed to systematically determine the extent to which the **HCI Quality Characteristics** of an **Interactive Computer System** meet the **HCI Evaluation Criteria** considered in the evaluation.	Rita's action of evaluating the web system login UI by observing and measuring Alex's interactions with the system.
HCI Evaluator	
The role played by an individual or organization responsible for conducting an HCI Evaluation.	Rita
HCI Evaluation Criteria	
A condition or capability (i.e., non-functional requirement) used to evaluate the **HCI Quality Characteristics** of an **Interactive Computer System**. HCI Evaluation Criteria that can be quantified can be related to **Measures** to quantify them.	EC1 - The number of requested help should be zero. EC2 - The number of wrong clicks or touches should be up to 2. EC3 - Time spent by the user on the first attempt to retrieve the password should be up to two minutes. EC4 - Time spent by the user on the second attempt to recover the password should be up to one minute. EC5 - The usability degree should be up to 5. Note: EC1 to EC5 are respectively related to M1 to M5 in the examples of **Measure**.
HCI Evaluation Report	

Table 1 – *Continued from previous page*

Concept	Example
Document that presents the results of an **HCI Evaluation** and other relevant information such as the considered **HCI Evaluation Criteria**.	The report created by Rita, which contains the evaluation results based on the measured values evaluated according to the specified criteria.
Measurable Entity	
An entity that can be measured and characterized by quantifying its properties (i.e., its **Measurable Elements**).	The web system (the web system is an Interactive Computer System, which is an entity that can be measured, therefore it is also a Measurable Entity)
Measurable Element	
Measurable property that characterizes **Measurable Entities** of a certain type.	Usability (it is a quantifiable HCI Quality Characteristic of Interactive Computer Systems and, thus, a property of the web system used in the university)
Measure	
A Measure quantifies a **Measurable Element** and characterizes a **Measurable Entity**. It is a function that enables the association of values (**Measurable Values**) to a **Measurable Element**.	M1 - number of calls for help M2 - number of wrong clicks or touches M3 - time to recover the password on the first use M4 - time to recover the password on the second use M5 - usability degree M1 to M5 quantify Usability (Measurable Element) to characterize the web system (Measurable Entity)
Measure Unit	
Unit in which a **Measure** is expressed.	Minute (for M3 and M4)
Scale	
Delimitates the range of values possible to be associated with a **Measure**.	For M1 and M2, the scale is composed of positive integer numbers (including zero) - i.e., the number of calls for help and the number of wrong clicks or touches can be equal to or higher than zero.
Measurement	
Action that measures a **Measurable Element** of a **Measurable Entity** by applying a **Measure** and obtaining a **Measured Value**.	When Rita measures the web system's (Measurable Entity) usability (Measurable Element) by counting the number of times Alex called for help (Measure) and obtained the value 3 (Measured Value).
Measurement Formula	
The formula that defines a **Measure** by quantifying its relations with other **Measures**. It is used to obtain a **Measured Value** in a **Measurement** that applies that **Measure**.	M5 = M1+M2+M3+M4
Measured Value	
The value obtained for a **Measure** in a **Measurement**.	The values 3, 2, 3, and 1.5 were obtained by Rita for M1 to M4. The value 9.5 was obtained by Rita to M5 by applying the formula presented before (see Measurement Formula example).