Improving the interoperability of 3D models among augmented reality systems: Proposal for a meta-model

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***Abstract*—3D models are essential components of augmented reality (AR). However a literature review of AR applications shows important shortcomings about 3D model interoperability (property of information/data to be exchanged). Lack of proper data structure and management strategy could cause substantial data loss and disability of AR systems to share a common perception of the real world. Correspondingly, studies on AR applications and existing 3D models state that consistent integration of AR systems is not achievable unless the process of modeling is formulated regarding real world and associated representations with respect to AR requirements. Accordingly, this research proposes meta-modeling as *modus operandi* to codify the required aspects of AR systems and the corresponding perception of world, and associate models with respect to each other. This paper presents this new meta-model and exposes some examples of its manipulation to improve the ability of designing better inter-operable AR applications.**

Keywords-3D model, augmented reality, interoperability, meta-model, semantics

I. AUGMENTED REALITY AND 3D MODELS

Augmented reality (AR) supplements reality by adding virtual features like graphics, annotations, images, sounds, videos, and other comments on the user's scene of reality in form of live video captures [3] [17]. For example, AR applications can add-on the name of surrounding buildings or subway lines on street surfaces as the user walks around. Building names and subway lines are virtual features as of annotations or graphical lines. They augment the view of the corresponding real objects like buildings or street surfaces as they appear in the live video stream captured by a smart phone. AR introduces a new way to surf the world. AR based applications are now an important part of several business models including education and training, video games, advertisement and marketing, urbanism and construction, military and so on [1].

Milgram has proposed a continuum that is often used to present and explain the various range of possible mixed reality where AR stands next to the augmented virtuality (Figure 1) [17]. AR occurs on the left part of this continuum as real environment is supplemented by virtual features. AR applications let the user immerses in a mixed environment where virtual representations become part of the real environment he observes.

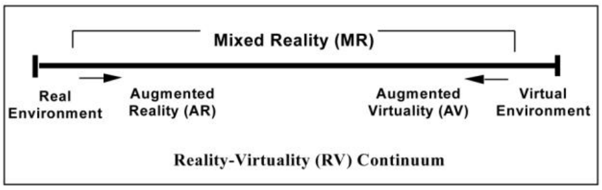

Figure 1. Millgram's continuum of mixed reality [17]

Some AR applications use printed markers that are previously embedded in the surrounding environment to tie virtual representations to the real world (i.e. prepared environment). Some like Layar [1] and Wikitude [2] (both are commercial tourist guides) augment the additional information at specific coordinates known as the points of interests (POI) in form of 2D or 3D annotations and graphics. Meanwhile, the AR applications developed by research laboratories try to relate interactions to objects and their individual or relative state (e.g. location, shape, movement, and color object) rather than a set of coordinate based POIs. The state of objects can be also defined with respect to each other. A door, for example, can be marked open if the door knob is not locked. Thus, the states of objects and their corresponding impressions on each other are considered in such experiences. Reitmayr and Schmalstieg present a collaborative AR application that relates augmented information to different building parts [21]. Their application identifies certain building parts as distinct features like specific windows, wall sections or famous stone carvings.

About the components of an AR, and as stated by Azuma [3], AR systems should combine real and virtual, be interactive in real time, and be registered in 3D. Many of AR actions are routed in 3D space and the use of 3D models becomes essential respectively [9] [25] [34]. The corresponding roles of 3D models in AR have been classified in three categories by Höllerer and Feiner: (1) improving the quality of augmentation with reach and realistic virtual features (2) 3D registration of augmented materials such as images, texts, symbols, and etc. (3)

[1] http://www.layar.com
[2] http://www.wikitude.org

figuring out the occlusions with respect to the observer's point of view [11].

In result, 3D models are widely used in AR applications. A literature review shows that many AR applications use pre-built 3D models that are packed in file formats like computer aided design (CAD) formats (e.g. STL, DXF, DGN) or 3D graphics (e.g. 3dsmax, obj). For example, Lee and Park have used 3D models in STL format in their CAD based AR prototype [15] or Liestol has employed polygonal 3D models in obj format [16]. Several researchers have recommend textual mark-up formats that are mainly designed for the transfer and visualization of 3D models among web based applications and often accepted as standards (e.g. KML and X3D). Wojciechowski et al. have established an AR based exhibition using X3D format to model and visualize museum objects [30]. Among mark-up formats, XML based formats have been much recommended. They are easily translatable and globally accepted in online and web protocols [4] [8] [11] [14] [22] [25] [26]. Indeed, only the Layar L3D [3] has been originally developed for AR applications. It is derived from obj files and comparatively contains simpler geometries. L3D is indeed developed for 3D rendering on mobile devices.

Although the existing 3D formats could resolve certain requirements of AR systems such as geometry, texture, transparency, and illumination, they are considerably weak in semantics and descriptive attributes that define and characterize objects [13] [29] [34]. World objects may have several definitions and functionalities regarding various domains of interest. In result, other sorts of 3D models have been established where geometric representations are classified on the basis of the corresponding semantics. Instead of only focusing on graphical or appearance aspects, semantic models have been designed to address the context in which the data are used [28]. These models manage various characteristics of spatial objects before the corresponding geometries. They have become global standards in different business models. CityGML for urban models [19] and building information modeling (BIM) for construction industries [18] are the well-known 3D semantic model examples.

The AR literature review states certain cases where 3D models are delivered in form of standard semantic models. The work of Woodward et al. employs Industry Foundation Class (IFC), the commonly used data structure for BIM [31]. Schall et al. refer to the use of geospatial databases among AR applications [26]. Structured databases or semantic information models suggest widespread inventory on geospatial objects. This could nevertheless be difficult to perform and time consuming regarding several domains of interest posing distinct classification over same groups of objects. Even in same domain there might be different levels of classification with respect to various application themes [33]. Briefly speaking, there exist several sources of 3D models but we estimate that none are formalized based on the geospatial perception of AR and the related semantics. In result, from a point of view of data exchange, AR systems interoperability is limited to the use of similar model extensions (e.g. X3D or CityGML). The concept of interoperability refers to "the ability of different users, software applications and computers to communicate/exchange data accurately, effectively, and consistently" [5]. Hence, we claim that a mutual frame that improves the interoperability of 3D models among AR applications is required to formalize the perception of AR systems regarding the real world and the supporting 3D models.

II. Need of Meta-Modeling in AR

Nowadays 3D models provide various types of abstractions representing real world phenomena as well as the relationships between them (e.g. building volume is bounded by number of wall facades or number of building solids situate on a land surface). They are indeed built in distinct domains of interest and are so specific to them.

Some initiatives suggest the definition of certain top level concepts that formalize the specification of model components known as meta-modeling [7]. For example, Fundamental Modeling Concepts (FMC) [4] meta-model has defined a consistent and coherent way to think and talk about dynamic systems in prior to specific system particles. A meta-model manages process of modeling by proposing a relevant formalism considering the various issues that affect models with respect to the global theme in which they are contained. Meta-models define different aspects of issues like system components, data, and etc. To better explain the relevance of using meta-models, a short illustration is taken from geographic information modeling. The ISO/TC211-19107 has defined the spatial schema for geographic information setting a mutual terminology for the spatial characteristics of real world phenomena [12]. The ISO-19107 has been the guideline for developing other geographical systems. CityGML (a data model) has used ISO-19107 spatial schema to address semantic abstractions of urban phenomena [19]. CityGML has been designed based on the Open Geospatial Consortium (OGC) GML which is compatible with ISO 19107 [19]. Indeed, CityGML is a semantic data model which has been developed following a certain spatial meta-model. CityGML abstracts urban objects considering the respective semantics while it is formalized by ISO/TC211-19107 as the corresponding spatial meta-model.

III. Presenting UModelAR

Our proposal suggests a meta-model that identifies and formalizes specific semantics and dependencies which are posed by AR environments on data models and 3D models as parts of that. Named as UModelAR, this meta-model unifies 3D models with AR environment in a top down order, from principal components of AR environments to the features that exist in the associated 3D models. As mentioned earlier, the issue of interoperability can not be satisfactorily resolved unless the architecture of the end-user application (i.e. AR applications) and the employed resources (i.e. 3D models) are formalized correspondingly. Thus, UModelAR aims to contribute to the following issues:

- Organizing the concepts and relationships that are posed on 3D models by AR;

[3] http://layar.pbworks.com/w/page/7783211/3D-objects-in-a-layer

[4] http://www.fmc-modeling.org/metamodel

- Defining the spatial nature of world and the associated models with respect to AR;
- Achieving a mutual perception of 3D models in AR regarding their corresponding uses;
- Increasing developers productivity.

UModelAR considers the most widely used definition of AR from Millgram's continuum (Figure 1) where AR environment consists of two principal components: (1) Reality as the physical (natural) environment where human lives and is addressed in form of live video captures and (2) Virtuality as the computer generated representations. Figure 2 presents the overall view of UModelAR which is later discussed in detail. Accordingly UModelAR includes five packages as (1) Augmented Reality Interface, (2) World and Associated Representations, (3) Acquisition of Physical Reality, (4) Model Localization, and (5) Model Description. Unified Modeling Language (UML) formalism has been used for all coming diagrams.

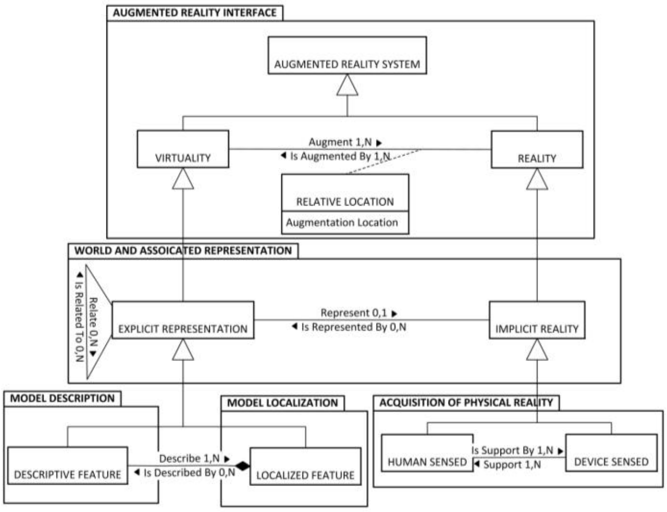

Figure 2. Overall view of UModelAR and the concepts it addresses

IV. AR CASE STUDIES TO SUPPORT THE DEMONSTRATION OF UMODELAR

In order to explain and present UModelAR two case studies of AR based applications will be used. These cases have been selected because they integrate 3D models or 3D geospatial data, are complementary from a point of view of usage and design, and both can benefit from interoperating with each other. Note that we were not involved in the design and implementation of these two AR applications.

The first example, ARhrrrr[5], is a marker-based AR game developed by Augmented Environments Lab (AEL) in the Georgia Institute of Technology [20] [32]. The storyline happens in a city attacked by zombies who capture running civilians. To build the game scene, a virtual 3D city model augments the real time video captured by a smart phone. The augmentation is managed by the printed marker that can be put anywhere. The 3D model includes streets, buildings and a central square. The zombies can capture the civilians only within the street area while the civilians move toward the central square where they are secured. Their movement (both zombies and civilians) is managed by the game engine. The user observes the game on the screen of his smart phone and shoots the zombies by targeting them. The user can also add street bombs to hunt down zombies by putting colored candies on the marker.

The second example, VIDENTE[6], has been intended for urbanism and is routed in unprepared maker less environments [27]. VIDENTE is connected to a geospatial database and augments the 3D model of relevant spatial objects like pipelines, buildings and walls on the surrounding scenery observed on an Ultra Mobile Personal Computer (UMPC). Here, the interactions occur with the augmented 3D model objects (e.g. walls, pipes). For example, the user can select an augmented pipe to view the related attributes.

At first glance, the mentioned case studies have no similarity apart from augmenting 3D models on the captured live video streams. Each of the given case studies perceives real world distinctly and use diverse representations. The 3D model employed by ARhrrrr is delivered by 3D file formats while VIDENTE employs a 3D model deriving from a geospatial database. They use completely different terminology to address the associated 3D representation of the corresponding world. In ARhrrrr, zombies catch civilian on streets while in VIDENTE streets are known as part of the transportation network. The ARhrrrr 3D model does not correspond to the real environment it augments while VIDENTE uses the 3D model of the corresponding real environment. Thus, regarding data modeling and 3D models, they are totally disjoint.

V. UMODELAR - AUGMENTED REALITY INTERFACE PACKAGE

AR systems, at first, consist of two main components as the reality and virtuality. Unlike existing approaches that do not semantically draw virtuality off the reality, different entities have distinct functionality to which they belong. As shown in Figure 3, UModelAR addresses **Virtuality** and **Reality** at the top-most package. The virtuality, in form of computer generated features, supplements the physical environment observed in form of live video streams (e.g. 3D representation of streets, buildings, zombies and civilians in ARhrrrr or pipes in VIDENTE). On the other side, the reality is the surrounding environment which is the target to the computer generated supplements.

[5] http://www.augmentedenvironments.org/lab/research/handheld-ar/arhrrrr

[6] http://vidente.grintec.com

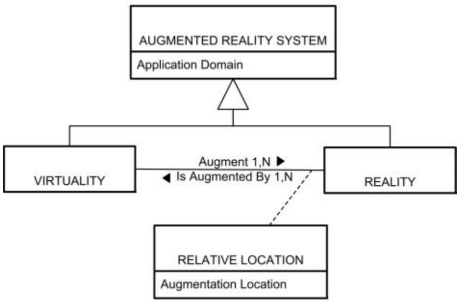

Figure 3. UModelAR – Augmented reality interface package

Consequently, a particular conjunction between these affiliate components accomplishes AR as the virtuality is superimposed on the reality and thus the reality is augmented by that (see the relation **Is Augmented By** in Figure 3). In AR, reality is the base to the superimposed virtuality[7] [3] [10]. AR is not achieved unless at least one instance of the reality is augmented by at least one instance of virtuality. In ARhrrrr, the marker is an instance of reality that is augmented by instances of virtuality. Normally, the virtuality augments the present reality. But in certain occasions the reality is not at the user's presence. For such cases the concept of approximate location [6] is issued by the **Relative Location** association class. For example, imagine the user walking on Laval University campus (Quebec City, Canada) with his or her iPhone in hand. Once, the AR application augments the Laval University campus on the live video stream that the iPhone captures while the user walks around the campus. In this case augmentation relative location is similar to that of the target reality. But if in the same condition the application augments a video stream coming from Paris (France), it is different to that of the target reality. In both mentioned case studies augmentation relative location is similar to that of the target reality.

VI. UModelAR - World and Associated Representation Package

There are certain phenomena that are not present in the employed 3D models but actually exist in the surrounding environment (e.g. trees for VIDENTE). These phenomena are not perceived by the AR system. Each system only perceives the specific part of the surrounding environment, as the target reality, which is represented to that. VIDENTE, for example, takes land and road surfaces as the target reality. Any scene of reality is implicitly similar to all AR applications. In fact they need an explicit representation to distinguish distinct parts of the reality. For sure any part of the reality that is not included in the given representations remains unknown and ineffective. In other words, every scene of the real world is similarly neutral to both of the given case studies (or any other AR system). They can not show any reaction to the real world unless some parts of it are explicitly represented to them. When represented, such parts become the only objects that can host the interactions or be used for other usages (e.g. 3D registration and occlusion management), like roads and lands for VIDENTE and the marker for ARhrrrr. Studies show that the state of interoperability is strongly associated with the state of mutuality between distinct perceptions. AR environments are identified by their relation to the implicit reality and the corresponding representations that explicitly model it. Internal relationships between system components and associated environments become clear and distinguishable for other systems if they are mapped by common identifiers. For this reason UModelAR defines the specific relationship among the main components of AR environment, the real world and associated models in this package as shown in Figure 4.

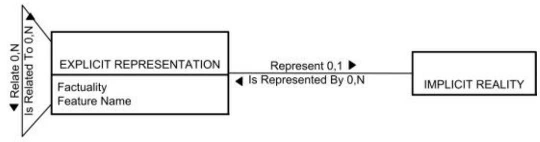

Figure 4. UModelAR – World and associated representation package

The **Implicit Reality** is the general scene of the surrounding environment and if abstracted to certain representations can form the target reality on which the virtuality is supplemented. Such abstraction forms the **Explicit Representation** which meaningfully connects the virtuality to the reality and produces a robust AR environment. In UModelAR the 3D model is a specific part of the explicit representation that is put in coherence with various semantics. In result different aspects of AR environments and associated features including geometry, appearance, movement, descriptive attributes and metadata are defined in relation to each other. UModelAR additionally introduces the specific semantics that are posed on 3D model objects by AR.

Certain parts of the explicit representation come from the implicit reality. Lands, roads and pipes in VIDENTE as well as the marker shape and texture in ARhrrrr are modeled based on the real objects which exist in reality. Meanwhile there exist other parts that do not come from the implicit reality, like anonymous buildings and streets of ARhrrrr which actually correspond to nowhere in the real world. Although they do not actually exist, they populate the supporting model at specific location, with specific shape, size and descriptive information. They are in fact the abstracted realization of the objects that come from the designer's mind. Therefore, the explicit representation can also include objects that are not associated with the real world. In order to make these items distinguishable the cardinality of the associated relationship between the implicit reality and the explicit representation starts at zero. By this trick, distinct AR environments become more understandable since the probable common parts (i.e. the parts that are associated with the real world) are easily accessible.

In UModelAR, the 3D model features can also be identified regarding their correspondence to certain real facts. In ARhrrrr, for example, the anonymous buildings and streets correspond with certain known facts (i.e. the concept of building or road) thus are factual. Zombies on the other hand are not factual because they do not match any real world fact. Factual representations (addressed by the **Factuality** attribute in Figure 4) can have the similar specifications (i.e. semantics) of the corresponding real world facts (e.g. thickness, material, similar geometry, and etc.).

[7] Also said as Integrate [3], Register [3], Projects [35]

VII. UMODELAR - ACQUISITION OF PHYSICAL REALITY PACKAGE

The reality can have different specifications regarding how it is captured and perceived. This can have certain impacts on the process of data modeling. Parts of the reality are captured by natural **human** senses. But since they are limited, different types of **sensors and devices** are developed to overcome this shortcoming (e.g. LIDAR, infrared sensors and radars). As seen in Figure 5, UModelAR identifies two types of implicit reality.

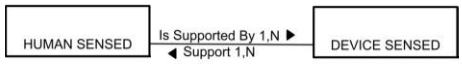

Figure 5. UModelAR – Acquisition of physical reality package

AR combines human and device sensed reality to build the target reality which is observed through the captured video streams. The triangle of the explicit representation, human sensed, and device sensed reality registers the AR environment in 3D. In ARhrrrr, for example, the marker is sensed by the mobile device and is matched upon the explicit representation of the marker in respective model. Based on that, the augmented graphics are presented to human vision through the live video stream captured by the handled device.

VIII. UMODELAR - MODEL LOCALIZATION PACKAGE

The Explicit Representation (3D model) covers a certain extent of space which is equal to the extent of the target reality. Position is the principal requirement of any feature that populates the model extent. Every AR system firstly requires locating the participating phenomena. Then it can decide the further actions, either to dismiss the features which are out of the sight from the temporary memory or to indentify objects shapes and sizes. Therefore, UModelAR refers to localization as the primitive spatial aspect of the features that volumetrically populate the model. **Localized Features** affect the geometry of AR world differently. Some are used as G**eometric References** for 3D registration and occlusion management or to define the functional extents. For example, in ARhrrrr the functional distance within which the user can hit the zombies is identified as the room where the marker is located. This extent is the ARhrrrr global extent. At the same time certain localized features, like symbols and annotations, are only applied for graphical augmentation and their corresponding shape and scale are not explicitly managed by the system. We call these kinds of elements as **Graphical Feature**. Figure 6 shows how UModelAR demonstrate the mentioned issues.

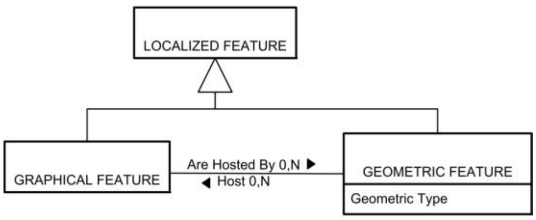

Figure 6. UModelAR – Model localization package

Geometric Feature is a central concept and its various specifications can be used to bring various scenario specific actions together. UModelAR identifies two types of localized geometric factures. The first type includes the features involved in the scenario hosting the application specific actions. These features define the spatial aspect of the associated scenario and are known as the UModelAR **Geographic Features** (e.g. civilian, zombie and street in ARhrrrr or road, land and pipe in VIDENTE).

Studies have shown that immersive AR experiences and the associated events are actually possible due to a particular spatial relativity among the geographic factures as they can be followed within a cyclic nested relativity [29]. This can be used to define the semantic hierarchy of various AR environments and the associated actions and behaviors commonly. In ARhrrrr, street nests zombie, civilian, and bomb while the central square only nests civilians as they can take shelter in it. Hence, the relative state (i.e. interactions) among them can be identified by the encompassing feature that nests the others. Similarly in VIDENTE, the urban area nests the land and the road. The land respectively nests the building and the pipe while the pipe is nested by the road as well. Finally, the rest of the geometric features that fall outside the corresponding hierarchy of each application domain are addressed as Parametric Features (e.g. marker and building in ARhrrrr). Figure 7 presents the overall view of the nested hierarchy of UModelAR geographic features.

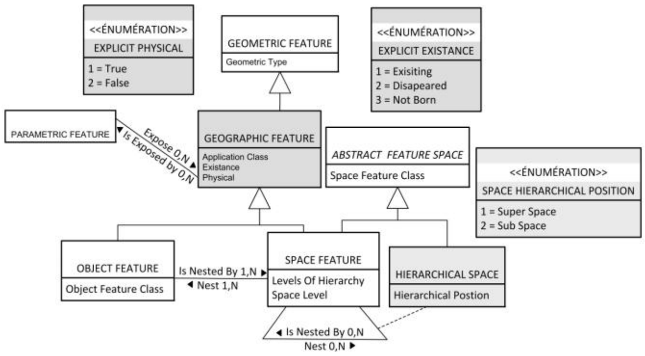

Figure 7. Representation of the nested hierarchy of UModelAR geometric features

UModelAR generalizes different behavioral relations between geographic features (e.g. pipes pass beneath several streets or humans walk on avenues) into the specific nested relativity as of the generalization of various relationships. Such hierarchy is accessible at the top, bottom, and middle of the hierarchy. UModelAR **Object Features** are defined as the lowest features in the corresponding hierarchy by which no further feature is nested (e.g. civilian in ARhrrrr or wall in VIDENTE). Meanwhile every UModelAR object may be nested by one or several other features. The features which nest others have been named the UModelAR **Space Features** (e.g. square and street in ARhrrrr or road and land in VIDENTE). Each UModelAR space, except the top most level space (e.g. room in ARhrrrr) may situate on one or many super spaces.

IX. UMODELAR - MODEL DESCRIPTION PACKAGE

The features that populate 3D models can be described by other complementary aspects as of metadata, appearance, attributes, and movement. Civilian and zombie in ARhrrrr for example can be recognized by their specific movement. Pipes in VIDENTE appear in simple colors while streets and buildings in ARhrrrr are draped by textures. The geospatial database used in VIDENTE also contains various attributes for each model object like the year of construction, usage, and etc. As shown in Figure 8, UModelAR addresses these types of information in model description package.

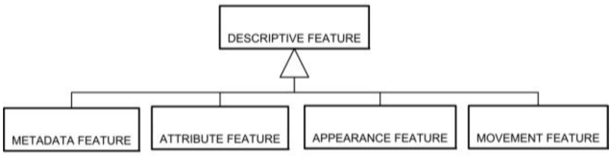

Figure 8. UModelAR - Model description package

X. THE USE OF UMODELAR

This section will now show how UModelAR can guide the process of modeling for AR systems and the associated 3D models. Both of the introduced AR applications are used to demonstrate the usefulness of UModelAR. Then the benefits of this approach are discussed. Figures 9 and 10 respectively present modeling of ARhrrrr and VIDENTE AR applications. Each phenomenon under studies becomes an UModelAR feature according to its role and functionality in the AR application.

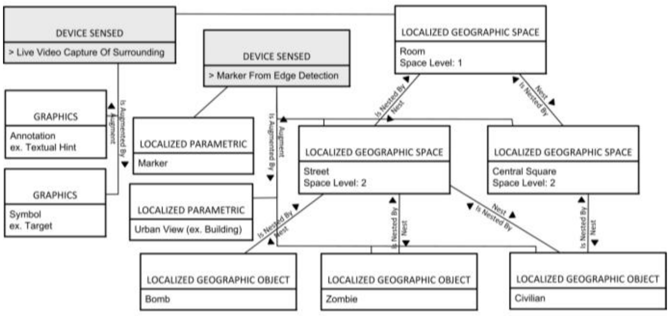

Figure 9. Meta-model of ARhrrrr based on the UModelAR guideline

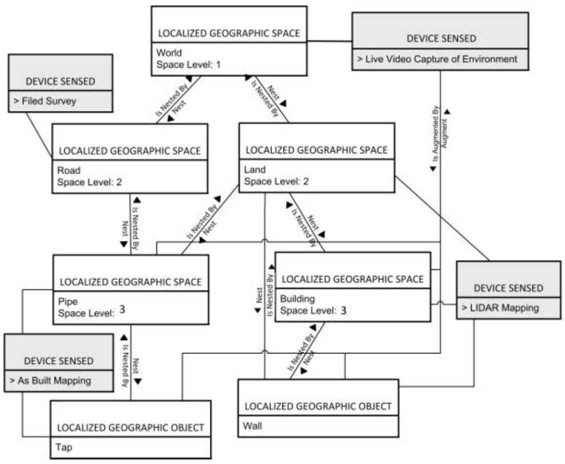

Figure 10. Meta-model of VIDENTE based on the UModelAR guideline

White classes show features that form the explicit representation and Gray parts are the corresponding implicit reality. Each 3D model contains numerous objects. Only those that are intentionally addressed by each AR application form the explicit representation of that application. Besides, the implicit reality calsses relate the 3D model to the target reality. Both of the case studies use device sensed live video capture. The classification of explicit representation and the implicit reality defines what parts of the sensed video can be recognized and interacted by the system. In ARhrrrr it is only the marker print. For VIDENTE it is any part that is presented by the geo-database.

As said earlier the elements that involve in application specific actions and events form a hierarchy of nested features accordingly. These are either UModelAR localized geographic spaces or UModelAR localized geographic objects. This hierarchy begins at the top most encompassing space with space level one nesting the whole scenario. For ARhrrrr, it is the extent in which the user is engaged with the game. In Figure 9, it is addressed by Room. In VIDENTE the top encompassing space is actually the extent of the supporting geo-database like a city, neighborhood, and etc. In Figure 10, it is known as World. Consequently street, central square, bomb, zombie and civilian become localized geographic features because they are involved in the game scenario.

Zombie and civilian do not nest any subsequent feature and are thus categorized as localized geographic objects. Street nests zombie and civilian and is a localized geographic space that occurs at space level two below the upper space that nests it (i.e. room). The action of capture in ARhrrrr occurs between zombie and civilian within the extent of the street. According to UModelAR this event is modeled by two types of features (i.e. localized space and object) and a relationship (i.e. nesting). All of the events that use the same UModelAR pattern can have similar equivalencies.

In VIDENTE the features that participate in the possible interactions are road, land, building, pipe, wall and tap. As UModelAR localized geographic features they nest each other consequently. Wall and tap are UModelAR localized geographic objects. They can be nested by more than one super space. In VIDENTE the pipes are nested by two UModelAR spaces (i.e. land and road) as they might occur in reference to any of them (e.g. a single pipe can pass below road and land in different locations). Walls might be either a certain building part or independently built on a piece of land. Therefore walls are also nested by two UModelAR geographic spaces (i.e. building and land).

In ARhrrrr, the virtuality is registered on the target reality by the use of the maker. The marker does not interfere in the game scenario and the related actions. It only localizes the game in respect to the surrounding reality. The marker is then a UModelAR localized parametric feature and regarding its role it is related to a class of implicit reality. This class of implicit reality is derived from the video stream captured by the smart phone to be matched by the marker feature. Every part of the 3D model which is registered on the reality by the marker (i.e. in ARhrrrr: the city model and the game elements that exist within it) is also related to this class of implicit reality.

Simillarly in VIDENTE, every feature from the explicit representation that corresponds to a real world object has be indicated. This permit the system perceives the captured reality. Corresponding classes of implicit reality define how each 3D model feature is logged and related to the target reality.

Let us now discuss the advantage of having done such meta-modeling of these two case studies from an interoperability point of view. From UModelAR modeling, it is at present quite easy to establish clear relations between geographic features and their respective hierarchy. In ARhrrrr the UModelAR localized geographic space that represents the room (i.e. space level one) nests two other spaces (i.e. road and central square). This pattern has two correspondences in VIDENTE, starting at space levels one (i.e. world space nests road and land spaces) and two (i.e. land space nests pipe and building spaces). The similarity among the nesting patterns may indicate possible links or relationships among AR applications. Hence the specific rules and events of each application that is defined with respect to this nesting pattern can be identified or implemented in the other system. For example, the action of capture in ARhrrrr needs a geographic space nesting two other features. Indeed, every similar pattern could host this action.

By this trick, the marker based environment of ARhrrrr can interpolate with the unprepared environment in which VIDENTE functions. The room, street and central square from ARhrrrr are not the same features that build VIDENTE environment, but their nested relativity pattern is identical to that of the word, land and road from VIDENTE. Thus, the features they nest (civilian and zombie) can be possibly hosted in VIDENTE by the mentioned features.

XI. Conclusion and Future Works

This work seeks improving the accessibility of 3D geospatial models among AR systems. Regarding the discussed requirements and shortcomings a meta-model approach has been suggested. The outcome, UModelAR meta-model, improves the data interoperability among AR systems by providing a mutual frame by which AR systems perceive the real environment and the associated representations in relevance to AR specific roles and uses. Thereupon, 3D model objects that are used for exclusive functions like 3D registration and management of occlusions can be now addressed regardless of the specific context of each model and the corresponding object dictionaries. UModelAR contributes to delivering the AR content regarding what it means and how it can be used. UModelAR consists of about 20 meta-classes, organized around 5 packages. To our knowledge, there exists no other similar meta-modeling proposal that addresses the issues of 3D model interoperability in the context of AR applications.

The experimentation with two case studies has shown that UModelAR is easy to apply. The mentioned concepts are not complex and do not depend on deep technical terminology or context specific definitions. UModelAR could thus help the communication between 3D model builders and AR designers by providing a common and simple language.

The nested relativity of geographic features as stated by UModleAR (i.e. UModelAR space/object features) shows a progressive approach in translating domain specific events and affordances into common model features and relationships. This capability put different parts of 3D models in relation to each other avoiding the expensive and incomplete 3D topology analysis.

The very important result of this new approach can be addressed in form of the following trade off: UModelAR makes model builders to add new specifications to their 3D models, but on the other hand frees considerable system resources. Indeed, complex processes like 3D feature mapping can be simplified in form of inteoprabable, reusable and portable patterns.

The given discussions only cover a number of possible frontlines. More precise evaluations are expected by examining various wide scale scenarios and applications. UModelAR is currently at its first level of evolution; implementation and validation are still among the main targets of the GeoEduc3D running research project. For instance, there exist this potential to deploy UModelAR as a certain schema or software plug-in to have it widely used by 3D model builders and AR designers and developers. Our recent investigations also indicate that UModelAR needs to address the time dimension as well. Finally, this investigation about 3D model interoperability has been undertaken for AR applications but UModelAR and the associated brainstorming could be a valuable source of understanding to other domains of expertise facing similar issues.

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