xR4DRAMA

Extended Reality For DisasteR management And Media planning

H2020-952133

D3.5

Semantic representation, fusion and reasoning-based decision support system for situation awareness

Dissemination level:	Public
Contractual date of delivery:	Month 13, 30 November 2021
Actual date of delivery:	Month 14, 1 December 2021
Work package:	WP3 - Analysis and fusion of multi-modal data
Task:	T3.5 - Multimodal information fusion T3.7 - Decision support system for media production and disaster management
Type:	Demonstrator
Approval Status:	Final version
Version:	1.2
Number of pages:	39
Filename:	D3.5_xR4Drama_SemanticRepresentationFusionDSS_20211201_v1.2.pdf

Abstract

Based on the requirements structured by WP6 and the dependencies incurring from the interaction with the other WPs, the purpose, scope, intended users and uses, and the

requirements of the xR4DRAMA ontology were identified. These specifications, along with the modelling understanding from relevant study fields, played an important guidance role for building the first version of the xR4DRAMA ontology that currently comprises modules for capturing the analysis results from the other modules of WP3 (visual analysis, stress level detection and textual analysis) Furthermore, it describes the population process of these incoming data to the repository of the ontology and presents some validation examples.

co-funded by the European Union

History

Version	Date	Reason	Revised by
0.1	22/10/21	First release of the template. ToC and assignments finalisation	CERTH
0.5	01/11/21	First round of contributions. State of the art, Modelling requirements, Conceptualization	CERTH
0.8	15/11/21	Second round of contributions. Multimodal fusion, Decision support, Validation	CERTH
1.0	26/11/21	Version ready for internal review by UPF	CERTH
1.2	01/12/21	Final version	CERTH

Author list

Organization	Name	Contact Information
CERTH	Spyridon Symeonidis	spyridons@iti.gr
CERTH	Haralampos Papadopoulos	chapapadopoulos@iti.gr
CERTH	Paraskevi Kritopoulou	pakrito@iti.gr
CERTH	Stamatis Samaras	sstamatis@iti.gr

Executive Summary

This deliverable describes primarily the process carried out in reach of T3.5 and T3.7, relevant to the development of the xR4DRAMA ontological framework, representation and multi-modal content mapping on semantic entities. Furthermore, it reviews the first methodological approach on the reasoning framework and the clustering mechanism.

Based on the requirements structured by WP6 and the dependencies incurring from the interaction with the other WPs (Analysis and fusion of multi-modal data, Platform development), the purpose, scope, intended users and uses, and the requirements of the xR4DRAMA ontology were identified. These specifications, along with the modelling understanding from relevant study fields, played an important guidance role for building the first version of the xR4DRAMA ontology that currently comprises modules for capturing the analysis results from the other modules of WP3 (visual analysis, stress level detection and textual analysis). Furthermore, it describes the population process of these incoming data to the repository of the ontology and presents some validation examples.

Abbreviations and Acronyms

Abox	Assertional Axioms
CQ	Competency Question
DL	Description Logic
ENVO	ENVironment Ontology
GIS	Geographic Information system
KB	Knowledge Base
MEMOn	Modular Environmental Monitoring Ontology
OWl	Web Ontology Language
ORSD	Ontology Requirements Specification Documents
RDF	Resource Description Framework
SOSA	Sensor Observation Sample Actuator
SPARQL	SPARQL Protocol and RDF Query Language
SPIN	SPARQL Inferencing Notation
SSN	Semantic Sensor Network
TBox	Terminological Axioms
WP	Work Package
W3C	World Wide Web Consortium
XML	Extensible Markup Language

Table of Contents

List of Figures

List of Tables

1 INTRODUCTION

This deliverable *D3.5"Semantic representation, fusion and reasoning-based decision support system for situation awareness"* focuses on describing a first view of the xR4DRAMA ontology, the fusion engine, and the decision support system. The ontology, also called "the xR4DRAMA Knowledge Base (KB)", is a knowledge representation model for semantically representing concepts relevant to the project.

The goal of the KB framework within WP3 is to research and develop technologies for semantic content and sensor input modelling, integration, reasoning, and question answering, as well as the fusion of the analyzed data. To this end, the information made available by WP3, regarding the delivering of multimodal recording mechanism, and from in later stage from WP4 with geographical data (GIS). The models that will be created will constitute for the reasoning mechanisms, taking into account the ontology vocabulary and infrastructure for capturing and storing information relevant to the xR4DRAMA application domain, such as: (a) Observation and Events (e.g., data collection of biometric sensors, visual analysis), (b) Spatio-temporal (e.g., highlighted locations and timestamps), (c) Mitigation and response plans in crisis (e.g., first responder teams).

The general architecture of the xR4DRAMA is depicted in Figure 1-1. The semantic representation repository is a central component in the system's architecture and hosts the xR4DRAMA, with the other components of the system interacting with it through the message broker.

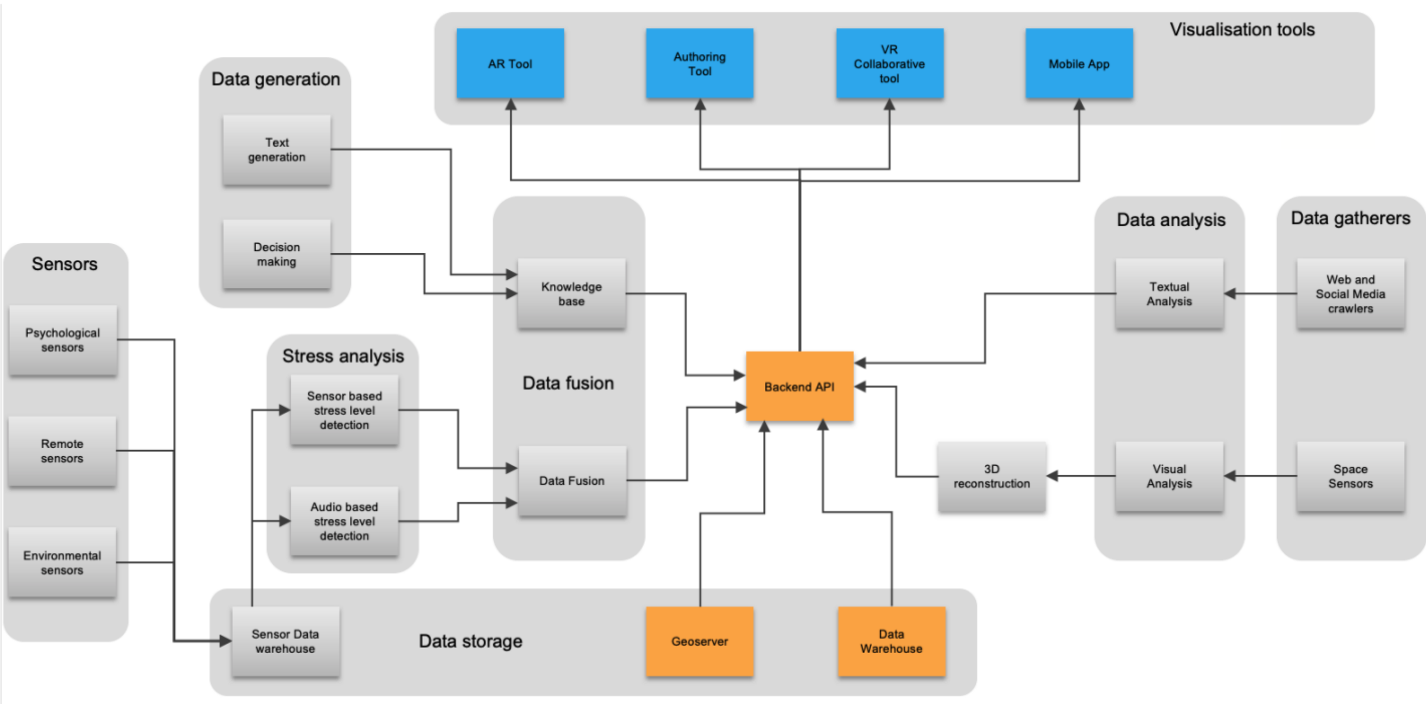

Figure 1-1 Architecture of the xR4DRAMA project

As for the architecture of the semantic integration component, it is illustrated in Figure 1-2.

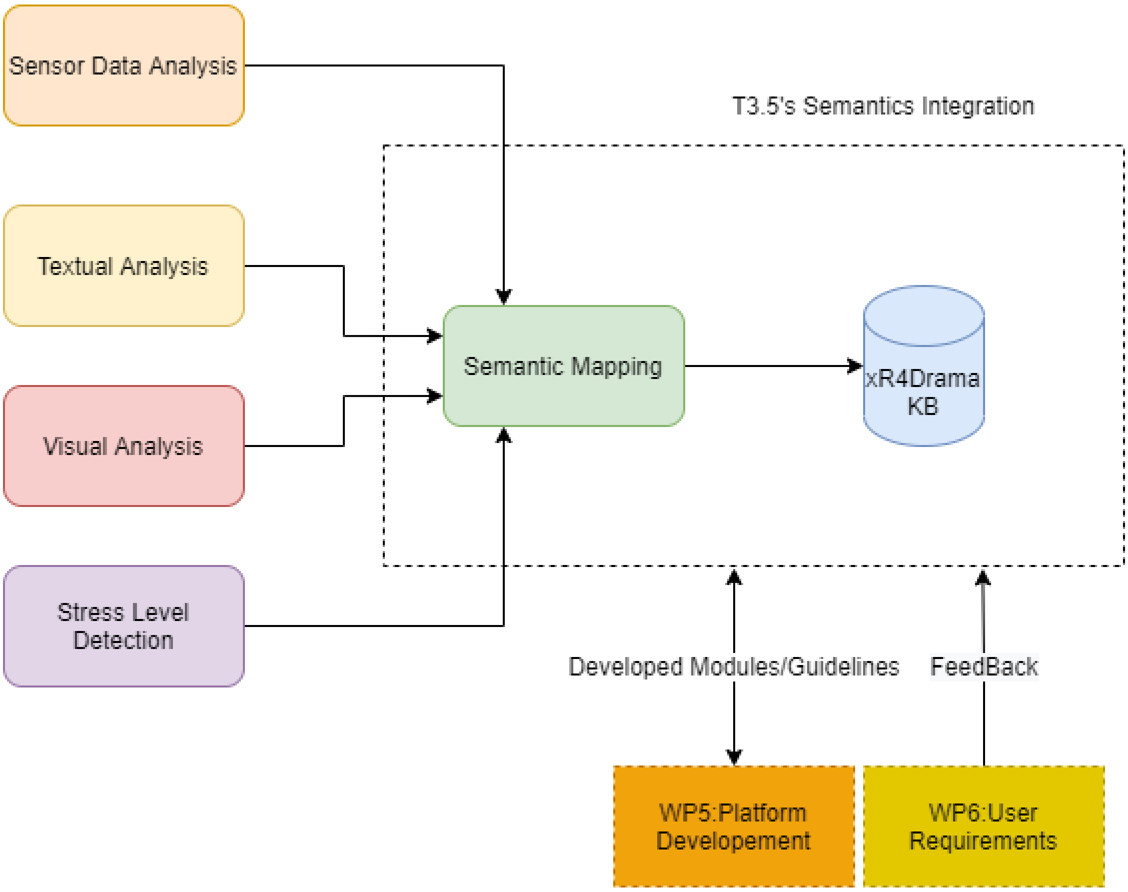

Figure 1-2 High level architecture of the Semantic Integration

The present deliverable reports on the work process carried out within Task 3.5 and focusing on the construction of the xR4DRAMA ontology. Section 2 reviews the relevant state-of-the-art with respect to knowledge representation languages, as well as already existing ontologies addressing project-relevant fields. Section 3 presents the requirements the ontology must meet; as detailed, their specification is mainly driven by the requirements set forth by WP6 (user requirements specification), while additional considerations come from the fore-described possible dependencies with WP4 and WP5. Section 4 reports on the ontology implementation and presents the status of the xR4DRAMA ontology. Section 5 presents an ontology validation example for an initial approach in the system's functionality. Section 6 contains some of the fusion theory as well as the semantic reasoning requirements and methodology. Finally, in Section 7, the document is concluded, presenting the conclusions that were drawn and discussing future work and further improvement of the module.

2 STATE OF THE ART

In this section we provide an overview on the state-of-the-art knowledge representation languages, already existing similar domain ontologies addressing relevant data to the xR4DRAMA project. More specifically, we present the core aspects of Description Logic (DL) language (Baade et al 2003) on which the official W3C recommendation for creating and sharing ontologies in the Web (OWL 2) is grounded, some of the OWL 2 categories, as well as relevant rule-based languages. Furthermore, a summary on the representative ontologies that have been proposed in the literature for modelling aspects relevant to the xR4DRAMA domain that fall into WP6's modelling requirements is presented.

2.1 Ontologies & Semantic Web

Ontology engineering has been widely used as an effective way for modelling specific domain knowledge because they can represent and organise information, context, and relationships more accurately. Additionally, they can be expanded/enriched by merging and combining parts of existing, relative, or not, ontologies into new ones. Ontologies are structures that are used to obtain knowledge regarding a domain of interest. Formally speaking, ontologies are explicit formal specifications of shared conceptualizations (Studer et al 1998). They show abstract views of the world including the objects, concepts, and other entities that are assumed to exist in some area of interest, their properties and the relationships that hold among them. Their formalization and expressiveness depend on the knowledge representation language used.

The Semantic Web-W3C, which is an extension of the current Web, aims to establish a common framework for sharing and reusing data across heterogeneous sources, ontologies play a fundamental part. The Semantic Web vision is to make the semantics of web resources explicit by attaching to them metadata that describe meaning in a formal, machine-understandable way. Web Ontology Language (OWL) (Deborah, McGuinnes 2004) has emerged as the official W3C recommendation for creating and sharing ontologies on the Web as the result of the previous effort. In the rest of this section, we present the basics of Description Logic (DL) language, on which OWL semantics are grounded, the different OWL species.

2.1.1 Description Logic

Description Logics is a family of knowledge representation language that may be used for a representation of knowledge of any application domain. This representation pattern is in a structured and formally understandable way. The name DLs derives from two features — the first one is the ability to describe a specific entity with the help of conceptual descriptions; the second one is to provide logic-based semantics.

It is usual for the DLs to include a terminological and an assertional formalism. A set of terminological axioms (TBox) is used to describe labels (or names) for more perplexing descriptions. For example, TBox may contain a description of a concept Mother:

$\text{Human} \cap \text{Parent} \cup \text{Mother}.$

On the other hand, a set of assertional axioms (ABox) is used for description of properties of individuals. For example, we can describe the relationship between two humans, Maria, and her son Alex:

hasChild(Maria, Alex)

DLs offer a reliable tool to deduce implicit knowledge from the explicitly defined knowledge with the help of TBox and ABox. The DLs provide well-defined semantics and powerful reasoning tools. For many years, there was a mismatch between the expressivity of DLs and the efficiency of reasoning. In other words, if a user wants to use a DLs, then he needs to establish a trade-off between the expressivity of DLs and the complexity of their inference capability. It means it is needed to restrict DL appropriately.

2.1.2 **Web Ontology Language**

The OWL belongs to the Semantic web, which has been created to represent plentiful and complex knowledge about things, groups of things and relations between things. OWL can be described as computational logic-based language. For this purpose, OWL can be easier for machines to automatically process and integrate information available on the Web.

OWL uses RDF's XML syntax (RDF/XML). OWL has adopted several features of RDF/RDFS meaning of classes and properties and those language primitives are beneficial to overall expressiveness. On the other hand, RDF and RDFS have very voluminous modelling concepts such as rdf:Property and rdfs:Class. Thus, RDF and RDFS may be restricted when a trade-off between expressive power and efficient reasoning must be established. There are three main kinds of OWL because of the trade-off mentioned above.

Different sub-languages are described in the following list:

- OWL Full: this kind of OWL represents the entire OWL language. This kind also offers the possibility to combine OWL primitives and RDF and RDFS. Moreover, the meaning of predefined primitives may be changed. OWL Full provides full compatibility with RDF, i.e., every valid RDF document is also valid OWL Full document. On the other hand, there is a possibility for the ontologies developed in OWL Full to be undecidable.

- OWL DL: this kind of OWL, where DL stands for Description Logic, restricts the application of constructors from OWL and RDF. The restrictions include: (1) Vocabulary partitioning, (2) Resources are allowed to be only one of specific type, i.e., a class, a datatype property, an object property, an individual, etc. Strictly speaking, a property cannot be a datatype property and at the same time object property and vice versa. The efficient reasoning is secured because of: (a) explicit typing of resources, (b) no transitive cardinality restrictions, (c) restricted anonymous classes. Furthermore, compatibility with RDF is lost. On the other hand, every valid OWL DL document is a valid RDF document.

- OWL Lite: is the last version that represents a restriction of OWL DL. The restrictions are, for example, excluding enumerated classes, disjointedness of classes, and cardinality (except the values 0 or 1).

2.1.3 Semantic Querying for Reasoning

As it was aforementioned, DLs, as well as OWL, exchange some expressiveness for more competent reasoning. The tree-model property is one such example. It conditions the tree-shape structure of models, ensuring decidability, but at the same time it severely restricts the way variables and quantifiers can be used, dictating that a quantified variable must occur in a property predicate along with the free variable. Consequently, it is not possible to describe classes whose instances are related to an anonymous individual through different property paths. To overcome OWL's limited relational expressivity and modelling shortcomings, the research body came up with the integration of rules with OWL.

The first step toward this was SPARQL, a language recommended by the W3C for extracting and updating information in RDF graphs. It is characterized by expressiveness with the ability to describe complex interactions and relationships between entities in a knowledge graph. The semantics and multiplicity of the SPARQL language have been reviewed in detail theoretically, showing that SPARQL algebra has the same expressive power as relational algebra (Perez et al 2006). Even though SPARQL is mainly used as query language for RDF, by using the CONSTRUCT graph pattern, it can define SPARQL rules that by combining existing RDF graphs into larger ones can create new RDF triples. These rules are defined in the interpretation layer in terms of a CONSTRUCT and a WHERE clause: the former defines the graph patterns, i.e., the set of triple patterns that should be added to the underlying RDF graph upon the successful pattern matching of the graphs in the WHERE clause. The SPARQL Inferencing Notation (SPIN) (Knublauch et al 2006) helps with the establishment of an easier expression and execution of SPARQL rules on top of RDF graphs. In SPIN, SPARQL queries can be stored as RDF triples together with any similar domain model, enabling the linkage of RDF resources with the associated SPARQL queries, as well as sharing and reusing them. SPIN supports the definition of SPARQL inference rules that can be used to derive new RDF statements from existing ones through rule application. A newer standard that has been developed as a tool to define structural constraints on RDF charts is Shapes Constraint Language (SHACL). SHACL consists of two parts: (1) a core that elaborates RDF vocabulary for the definition of shapes and variables and (2) SHACL-SPARQL, which is a mechanism for expanding the SPARQL.

2.2 Related Ontological Frameworks

The scope of this subsection is to present the state-of-the-art ontologies that can be used for modelling aspects relevant to the xR4DRAMA's domain of application. According to the xR4DRAMA ontological requirements, which will be reviewed in the following section, we have categorized the relevant ontologies into four domains. First, the ones that can be used to model events and observations. Next there are the crisis management ontologies (modelling risks and mitigation) followed by the disaster ontology and finally the ontologies for general purposes; temporal and geospatial. We should say at this point that the purpose of this section is not to provide a complete list of the ontological structures related to the xR4DRAMA's domain, but to highlight on design concepts and entities that have been proposed or used in systems for modelling and conceptualization.

2.2.1 Observation and Events

The mapping of sensors and their observations, properties and features of interest has been in the centre of many research approaches. Into this, the dominant ontologies are the Semantic Sensor Network (SSN) (Compton et al 2012) and Sensor Observation Sample Actuator (SOSA) (Janowicz et al 2019). They have been applied in various use cases, applications and scenarios, including satellite imagery, large-scale scientific monitoring, industrial and household infrastructures, social sensing, citizen science, observation-driven ontology engineering, and the Web of Things.

The ontology that was studied is Modular Environmental Monitoring Ontology (MEMOn) (Masmoudi et al 2019). MEMOn is based on other ontologies, namely the Basic Formal Ontology (BFO), the ENVironment Ontology (ENVO) (Buttigieg et al 2013), the Semantic Sensor Network Ontology (SSN) and the Common Core Ontologies (CCO). In Figure 2-1 it is shown that the ontology offers eight main modules (Disaster, Temporal, Environmental material and process, Sensor, Observation Geospatial and Infrastructure) covering more aspects than the ontologies to represent different emergency incidents.

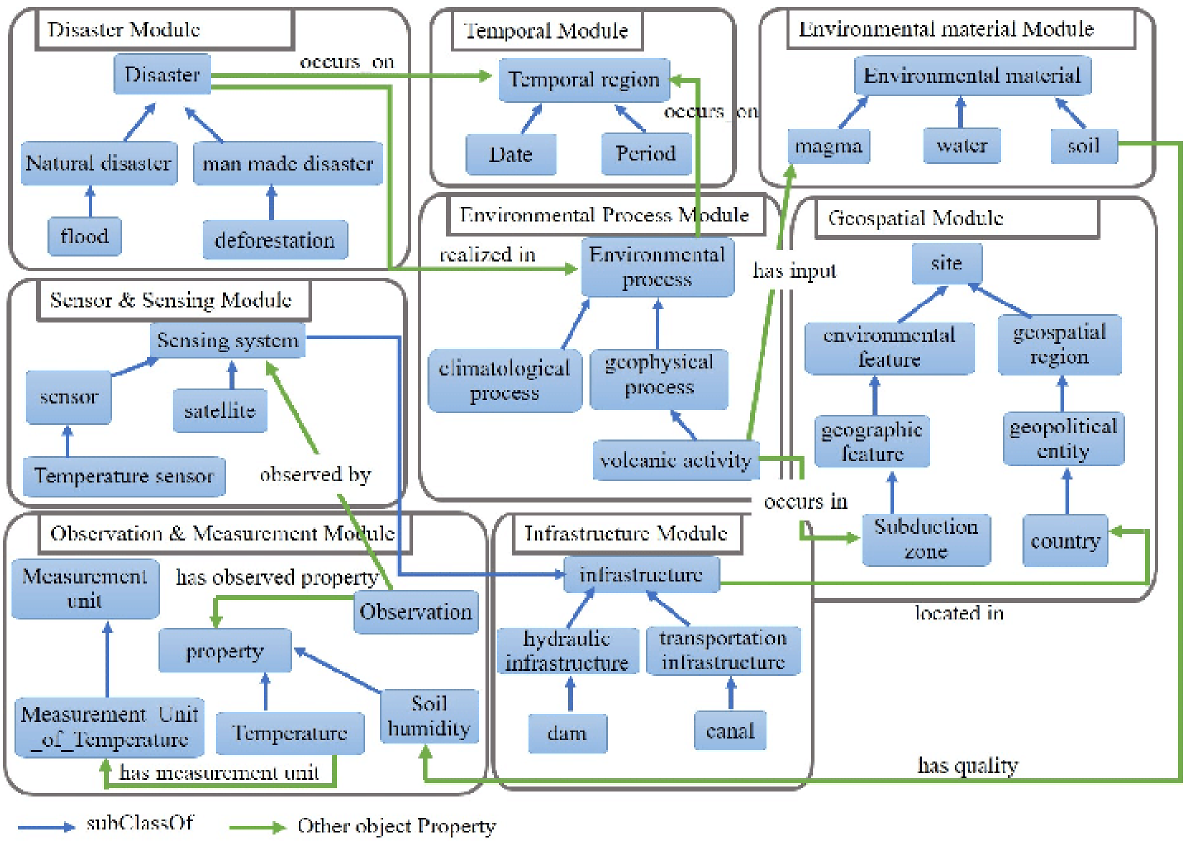

Figure 2-1 MEMOn Ontology

2.2.2 Multimedia Context

Multimedia Object Description ontology (Choudhury et al 2008) in Figure 2-2 is aimed to integrate the multimedia objects on the web with other information objects to give an interlinked and integrated view of the user information needs. This is only possible when we model not only the media object used to represent the content but also the content abstracting the higher semantic concepts of specific domain. The basic entities that are described through this ontology are:

- Multimedia Objects: with four subclasses, like Video, Audio, Image, Segment.
- Feature: to describe the audio and visual characteristics of the data.
- VisualConcept: a class for describing semantic concepts in a higher level. They can be simple (car, human) or complex (flood, explosion).
- Event: describes the semantic content in terms of events, which is interplay between objects and actions or other sub-events. Event detection is a challenging issue for multimedia processing and retrieval community.
- Location: two types of location, as depicted in the media, such as City, and spatial location, such as coordinates.
- Segment: is the broader class for both spatial segments and temporal segments, such as image region, frame and shots, audio segments.

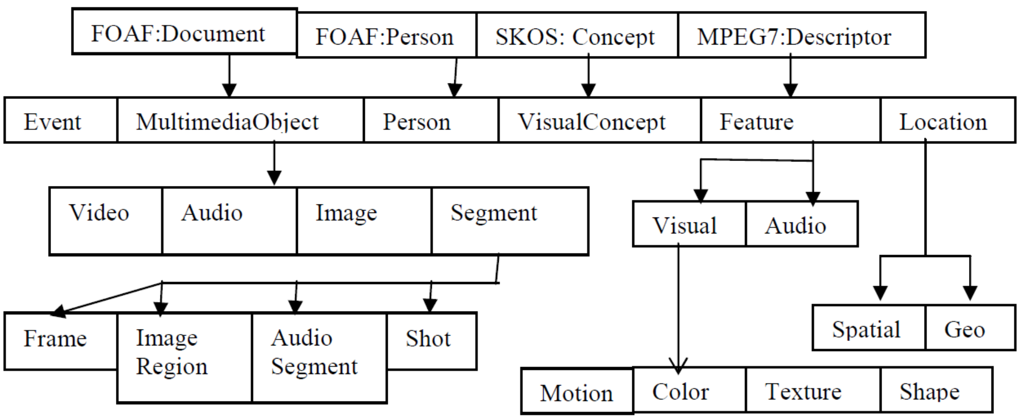

Figure 2-2 Multimedia Ontology

2.2.3 Crisis and Disaster Management

The construction of context information for the disaster management ontology (Hoill Jung et al 2015) is divided in three different sections. The external context information, which contains the environment, location, and equipment information. The internal context information, which takes inputs from users and their personal and position information. And finally, the service context information, which is divided into guidelines and location service information. Figure 2-3 shows the person-based relations with other classes, and it consists of internal ontology and external ontology. Therefore, the information for personalized service is drawn and offered through service state, user position, device operation, context information about disaster, and user environment information.

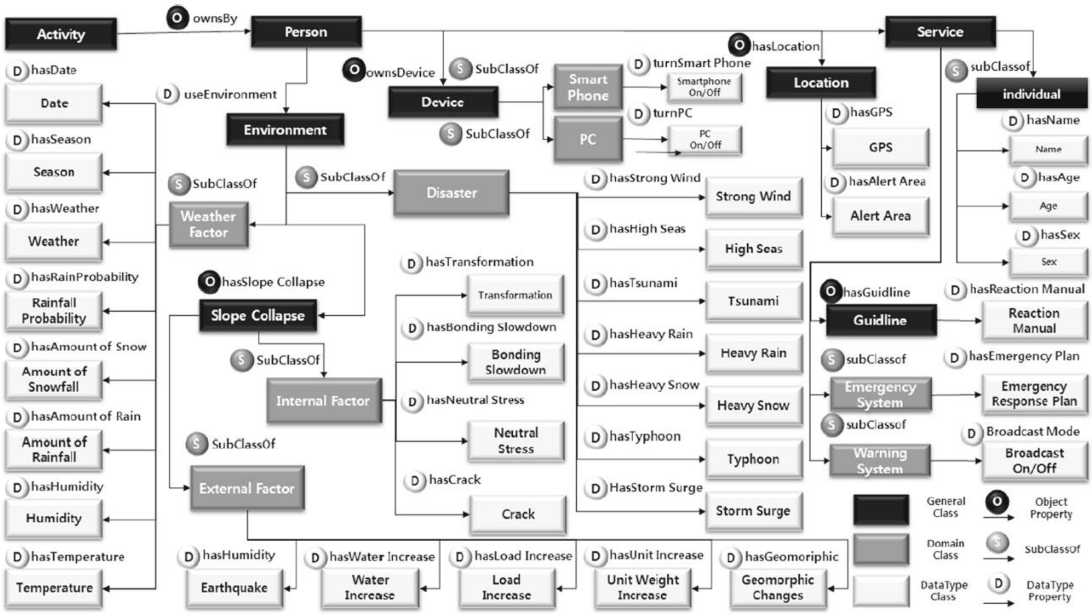

Figure 2-3 Disaster Management Ontology

As for a more specific example of a disaster ontology, we mention here the Flooding Knowledge Graph (Son j et al 2021). In Figure 2-4 it is illustrated the structure of the graph that utilizes concepts from different sources (e.g., Wikidata[1], DBpedia[2]) to describe suitably entities like “cause” and “effect”. Also, this ontology is a good example to present the interlinking with other knowledge graphs as a high compatibility feature.

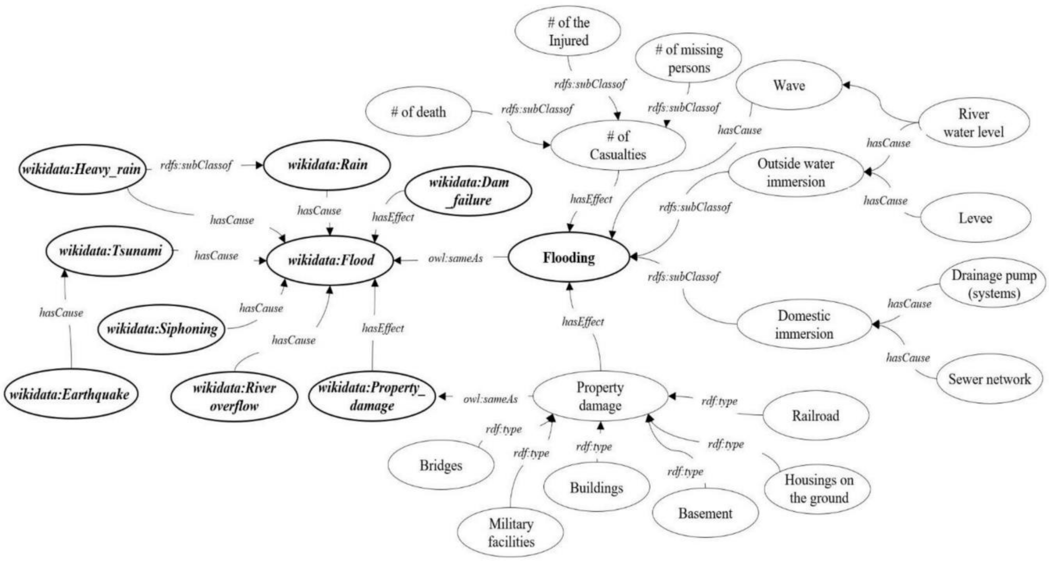

Figure 2-4 Flooding Ontology

[1] https://www.wikidata.org/
[2] https://www.dbpedia.org/

2.2.4 Time and Geospatial Data

In semantic web there are two standard ontologies of temporal concepts, OWL-Time (Hobbs et al 2004) and time-entry (Pan et al 2004). They both provide similar vocabularies for expressing facts about temporal intervals and instants, while time-entry also includes the concept of an event. In addition, the ontologies include classes and relations for expressing time intervals and instants in clock and calendar terms. Both include the concept of a time zone, and a separate global time zone recourse in owl is available.

The importance of the geospatial data (e.g., locations, distances, coordinates) and their semantic representation is recognised by the research, because they offer solid methods for retrieving information that are used in several GIS applications. There are many geographical ontologies that are used to express semantically geographical and spatial information. One of the most prominent of them is the GeoSPARQL. The later defines an RDF/OWL vocabulary for representing the aforementioned information and elaborates them with the use of a query language with powerful rules and functions, which allow precise semantic reasoning.

3 MODELLING REQUIREMENTS

In this section we describe the roadmap and the methodologies followed to collect the modelling and reasoning requirements, as well as a description of the results of this approach. Additionally, there is an effort on the association of the modelling and reasoning requirements with technical & user requirements.

3.1 Methodology

The methodology that we followed to formulate modelling and reasoning requirements for the xR4DRAMA KB can be visualized with the use of structural blocks of developing actions. In Figure 3-1 there is a high-level review of these milestones.

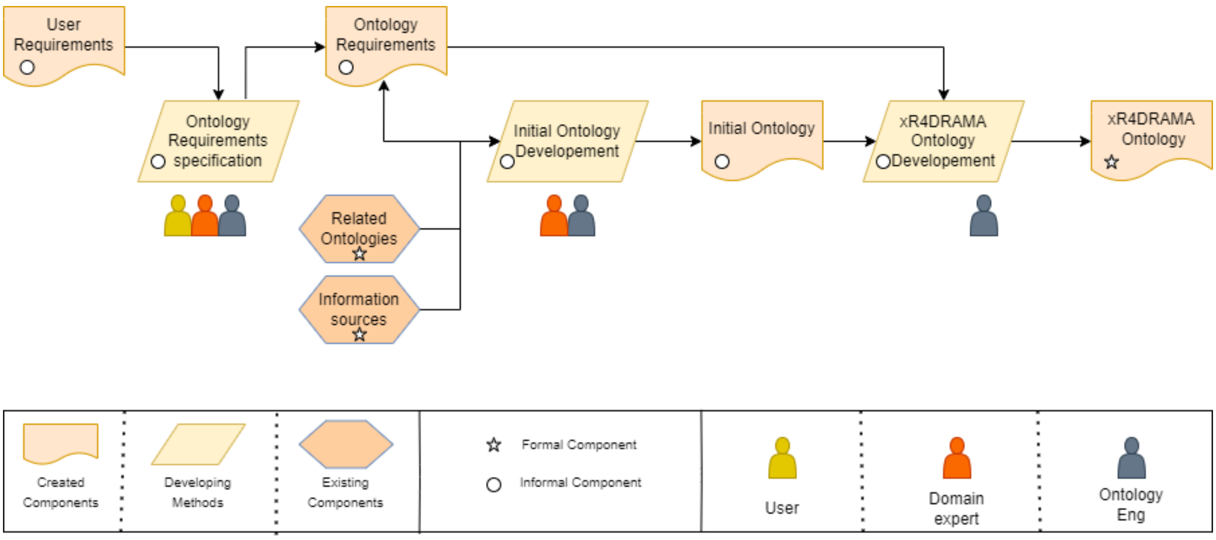

Figure 3-1 Methodology for requirements elicitation

The process that was followed can be divided into three major stages with several possible inputs and outputs.

1.The first stage is focused on ontology requirements specification and the retrieval of ontology requirements specification documents (ORSD, described in the following section). In this stage the role of end users is of great importance. They will provide insights regarding the user requirements. Additionally, domain experts will help understand the use cases and find the optimal matching with the ontology requirements. Finally, ontology engineers have a more consulting role in this stage regarding the process execution.

2. The second stage, after the acquisition of ontology requirements, involves the development of an initial ontology making a good use of related ontologies of the same domain, and information from several outputs of the xR4DRAMA system, which have filtered with the results of the first stage. The role of the ontology engineers here is major, whilst he translates the domain experts' findings into a machine interpretable format.

3. The third stage contains the expansion of the initial ontology with the use of more advanced design patterns and further specification of the incoming information, with the use of the OWL to finalize the xR4DRAMA ontology.

3.2 Ontology Requirements Specification

As we mentioned before, the important role in the first stage of the methodology that followed, was the Ontology Requirements Specification Document (ORSD) (Suarez-Figueroa et al 2009). This is a template-based report in which we determine which are the domain and the scope of the ontology. Additionally, this document helps us to specify why the ontology is needed in the project, what are the intended uses, who are the end users, what the ontology should fulfil, and the verification, grouping and prioritization of requirements.

3.2.1 Ontology Requirements Specification

The template of a ORSD contains the following fields where you can find information regarding the purpose, scope, implementation language, intended end-users, intended uses, requirements, and pre-glossary of terms of the ontology that is being built:

- <u>Purpose</u>: The main general goal of the ontology/main function or role that the ontology should have.
- <u>Scope</u>: The coverage and the number of details that the ontology should contain.
- <u>Implementation Language</u>: The formal language that the ontology should have.
- <u>Intended End-users</u>: The intended end-users expected to need the ontology.
- <u>Intended uses</u>: The intended uses expected for the ontology.
- <u>Ontology requirements</u>:
    - Non-functional requirements: The general requirements or aspects that the ontology should fulfil, including optionally priorities for each requirement
    - Functional Requirements: Groups of Competency Questions (CQ): The content specific requirements that the ontology should fulfil in the form of groups of competency questions and their answers, including optional priorities for each group and for each competency questions (Noy & Mcguinness, 2001).
- <u>Pre-glossary of Terms</u>:
    - Terms from Competency Questions: Items that included in the competency questions and their frequencies.
    - Terms from Answers: The terms that included in the answers and their frequencies.
    - Objects: The objects that included in the competency questions and their answers.

3.2.2 xR4DRAMA OSRD

The xR4DRAMA ORSD is based on the use cases scenarios and requirements laid out in D6.1 "Pilot use cases and initial user requirements" and in D6.2 "Final user requirements". Additional feedback and clarifications have been elicited through iterative cycles of communication with WP3, WP4, and WP5 that extended equally and were qualified to provide supplementary analysed input that ultimately came to further refined and unambiguous requirements. Therefore, the previous process results in the ORSD that reflects the ontology requirements as pertinent to the status of the xR4DRAMA system. It is possible that some revisions and extensions will need to be carried out as the system functionalities evolve. Table 3-1 constitutes the xR4DRAMA ORSD.

1	**Purpose**
	As the purpose of the xR4DRAMA semantic representation framework we can define the structures and the vocabularies that are used to capture the analysis results coming from other components. The system needs the ontology to secure interoperability and reusability between the individual modalities and to support, together with inference rules, personalised (based on the users) interpretation services. The KB will be the crossroad between the sensor data inputs and the backend.
2	**Scope**
	The ontology has to focus just on the following aspects: • Representation of the analysed data from Stress Detection sensors. • Representation of the analysed data from Visual Analysis tools. • Representation of the analysed data from Text Analysis tools. • Representation of the georeferenced data. • Representation of the analysed data from mobile application.
3	**Implementation language**
	The ontology will be implemented in OWL 2, presented in previous section, the officially recommended language by W3C for knowledge representation in the Semantic Web.
4	**Intended End-Users**
	• **PUC1: Authoring Tool** Displaying Messages to the authoring tool regarding an emergency situation, so the specific mitigation actions to take place.
5	**Ontology Requirements: Functional Requirements - CQs**
1. Analysed Data 1.1. What is the severity of the observation [X]?	

1.2. What is the risk level of the observation [X]?
1.3. Which is the emergency in the observation [X]?
1.4. What is the detection/creation time of the observation [X]?
1.5. Which is the area in the observation [X]?
1.6. What is the probability of the area in observation [X]?
1.7. Which is the Stress level of the between time intervals [t_1]-[t_2]?
1.8. Which is the objects found in video[X]?
1.9. Which is the simmoid in video[X]?
1.10. What is the multimedia type used in observation [X]
1.11. Which is the most/least risky observation?
1.12. Which buildings where detected between time intervals [t_1]-[t_2]?
1.13. What is the probability of a detected building/object?
1.14. Which observations occurred after time [t_1]?
1.15. How many people are in danger between time intervals [t_1]-[t_2]?
1.16. How many vehicles are in danger between time intervals [t_1]-[t_2]?
1.17. How many open areas are between time intervals [t_1]-[t_2]?

2. Geospatial Data
2.1. What is the location of the FR[X]?
2.2. What is the location of the observation[X]?
2.3. What is the location of the citizen-user[X]?
2.4. Which observation has location[X]?
2.5. What is the project location[X]?
2.6. How many citizens[X] are close to the specific location?
2.7. How many FR[X] are close to the specific location?
2.8. What is the location of the safe area ?
2.9. What is the location of the risk area?
2.10. Which are the coordinates of a safe route?

3. Project Data
3.1. What is observations related to the project[X]?
3.2. What is the id of the project [X]?
3.3. What is the RiskReport of the project [X]?
3.4. How many citizens are in the specific project[X]?
3.5. How many FR are in the specific project[X]?

Table 3-1 xR4DRAMA OSRD

4 xR4DRAMA Knowledge Base

In this section, the content of the first version of the xR4DRAMA ontology is presented. The development of the classes, properties and individuals has been structured in accompany with the competency questions that we reviewed within the previous section. Furthermore, whenever it was possible on a conceptual level the related standards and ontologies drew guidelines that we followed. The formalization of the ontology is based in the SSN/SOSA ontological framework, and it was used as a domain ontology.

4.1 Conceptualization

4.1.1 Reuse of existing resource

For dealing with semantic heterogeneity in complex systems like xR4DRAMA, Semantic Web technologies were chosen for building a suitable solution. Semantic Web Technologies represent one of the promising ways to ensure interoperability, as discussed in Chapter 2. One of its approaches in providing the suitable outcome is by making good use of similar domain ontologies.

Semantic Sensor Network (SSN) ontology is introduced, and this ontology may be utilized for a description of sensing devices as well as related processes. The SSN ontology is based on the ontology design pattern called Stimulus-Sensor-Observation pattern. The SSO was designed as the cornerstone for heavy-weight ontologies for the Semantic Sensor Web applications. This pattern is also aligned to the Dolce Ultra-Lite ontology, a very common framework that is used as an upper ontology. The architecture of SSN ontology together with the dividing to modules is illustrated in Figure 4-1 .

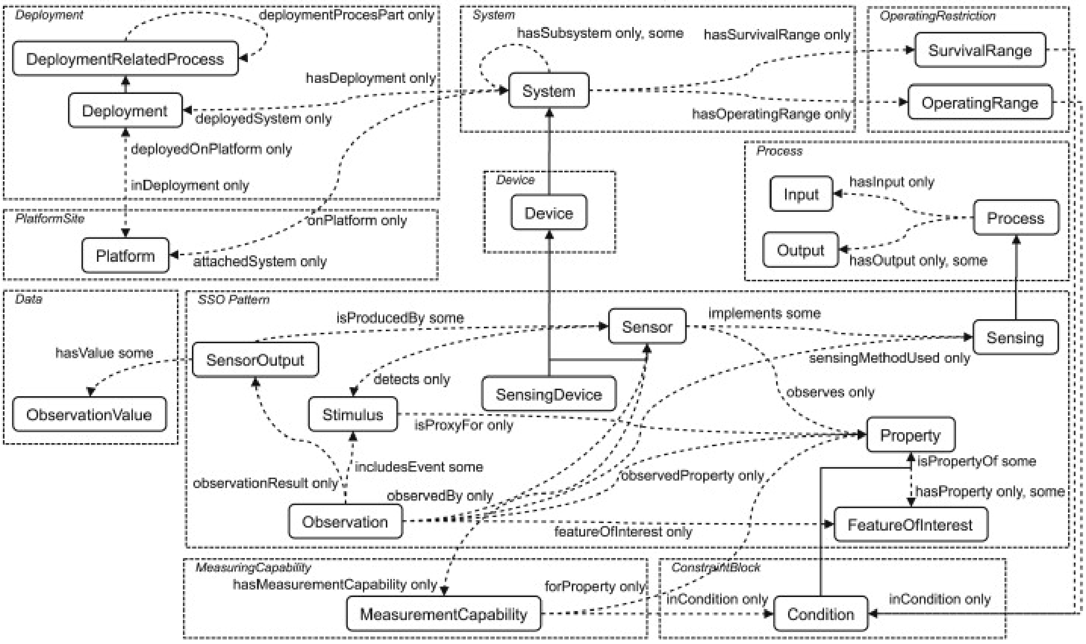

Figure 4-1 SSN ontology graph

SSN ontology is composed of several modules that are fundamental in the sensor representation domain. The module Skeleton represents the core conceptualization as a lightweight ontology with a minimal commitment. This part includes the main concepts, such as *Sensor*, *SensorOutput*, *Observation*, *SensingDevice*, and Sensing. Next, the module Process represents processes together with their inputs and outputs. Besides of the main modules, SSN is also composed of following modules — *MeasuringCapability*, *ConstraintBlock*, Device, *OperatingRestriction*, *System*, *Deployment*, *PlatformSite*, and Data that are not relevant at this point in the xR4DRAMA conceptualization.

A major role in the conceptualization played a newer version of the SSN, the Sensor, Observation, Sample, and Actuator (SOSA), which is a lightweight version that incorporates Actuators and it is not based on the DUL ontology. This allows the representation of:

- **Sensor**: A sensor is any entity that implements a sensing method and thus observes some property of real-world entities (things, persons, events, etc). Sensors may be physical devices, computational methods, a laboratory setup with a person following a method, or any other thing that can follow a sensing method to observe a property.
- **Observations**: They can be considered as the connection among stimuli, sensors, and their outputs. In SSN/SOSA, observations are rather contexts for the interpretation of the incoming stimuli than physical events, in contrast to O&M, where observations are interpreted as events.
- **Feature of interest**: A feature is an abstraction of real-world phenomena that are the target of sensing, e.g., a person.
- **Procedure**: Procedure is a description of how a sensor works, e.g., a description of the scientific method behind the sensor. Sensors can be thought of as implementations of sensing methods to derive information about the same type of observed property.

4.1.2 Design

Here it is presented detailed conceptualization of the ontology design and the entities that we form. As it is already mentioned, the concepts introduced by the SSN ontology are quite important for sensors, observations, sensing devices, their relationships, etc. Thus, additional concepts have to be designed in order to cover the multifaceted nature of the knowledge that was previously presented as CQs. The following graphs visualize with simplicity the new concepts that were integrated, starting from a higher level, and gradually reaching the lower-level entities of the ontology. The methodology followed was based on the Modelling OWL Ontologies with Graffoo.

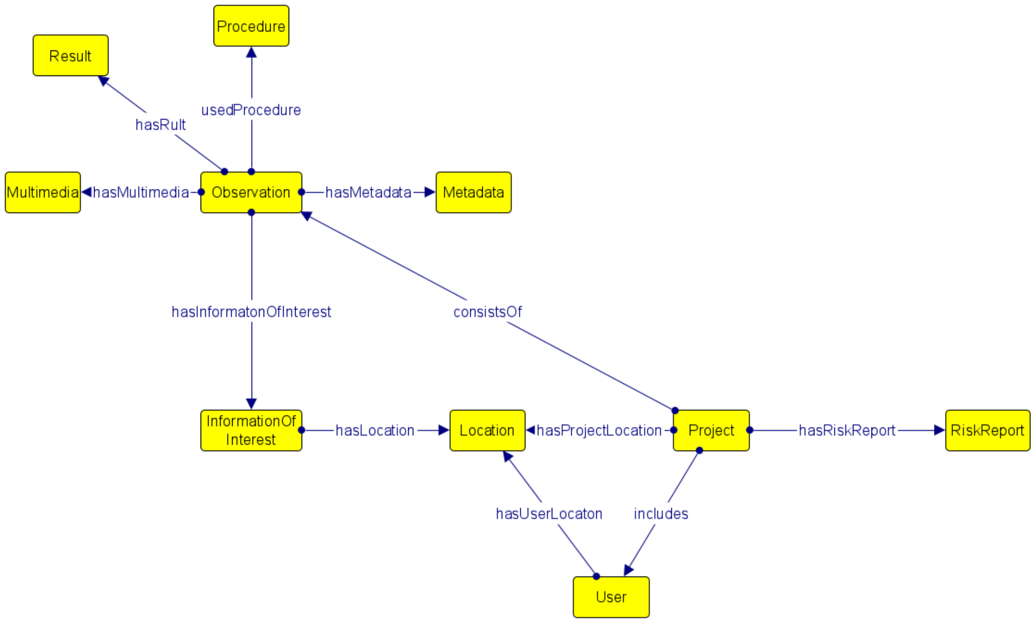

Figure 4-2 xR4DRAMA Ontology high level

Figure 4-2 Illustrates an overview of the core ontology classes. We wanted to make it simpler, so we have omitted data type and inverse properties, as well as extensive class hierarchies. These entities are the foundation of the initial version of the ontology. Figure 4-3 shows a list with the total amount of classes that are modeled in the KB.

- **InformationOfInterest**: The basic entities of interest to facilitate the decision support.
- **Location**: This class represent the geographical area where something happens. It can be presented with coordinates or with the name of the location (e.g., Vicenza).
- **Metada**: All the secondary information that comes with the analysis results and can be used in the decision-making process.
- **MultimediaObject**: The type of the mean that is used to transform information it can be rather Audio, Textual, or Video.
- **Procedure:** This class describes the process of analyzing the date and is used by each respective component.
- **Project**: The class describes each operation and some data regarding them.
- **RiskReport**: This class describes the aggregated result of all the risk levels that derive from the different components.
- **Sensor**: Some information about the sensors that are used during a project.
- **User**: A user can be a responder or a citizen. Each one of them has different outputs of data to feed the KB.

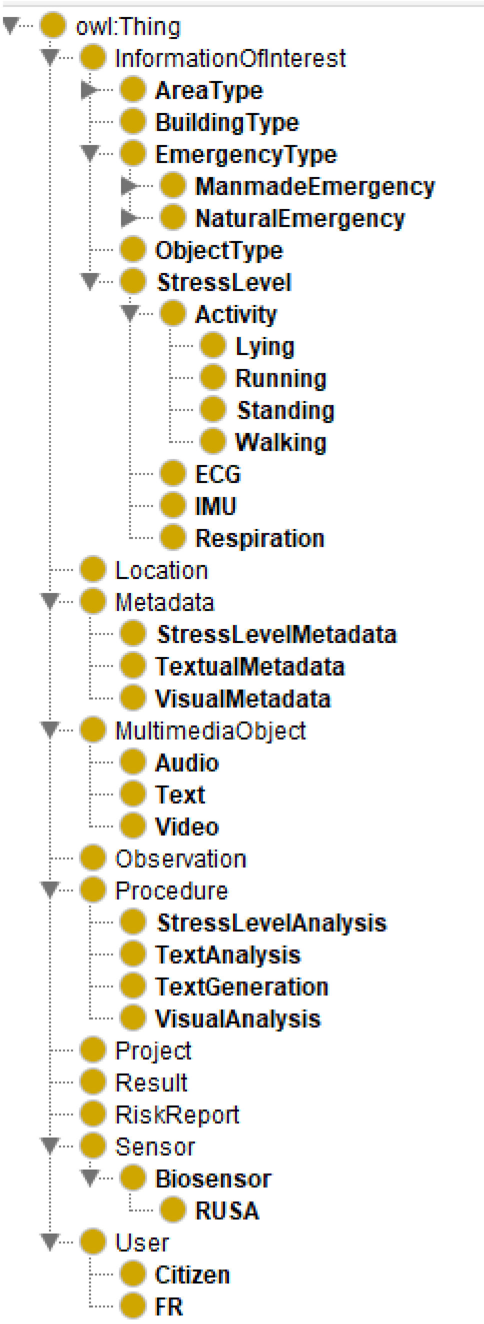

Figure 4-3 XR4DAMA list of entities

In Figure 4-4, a more detailed view of the core classes is presented, with the additions of datatype properties.

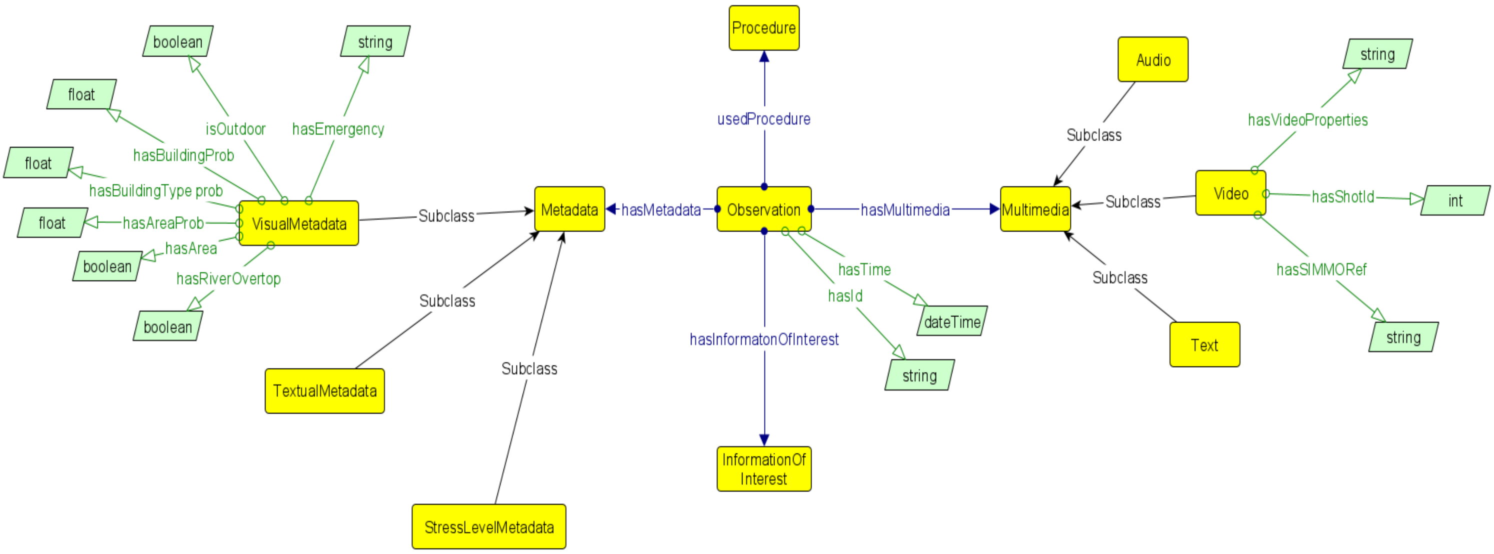

Figure 4-4 Detailed overview of multimedia branch

Then, in Figure 4-5, we have the specific data of an instance mapped from inputs from visual analysis component.

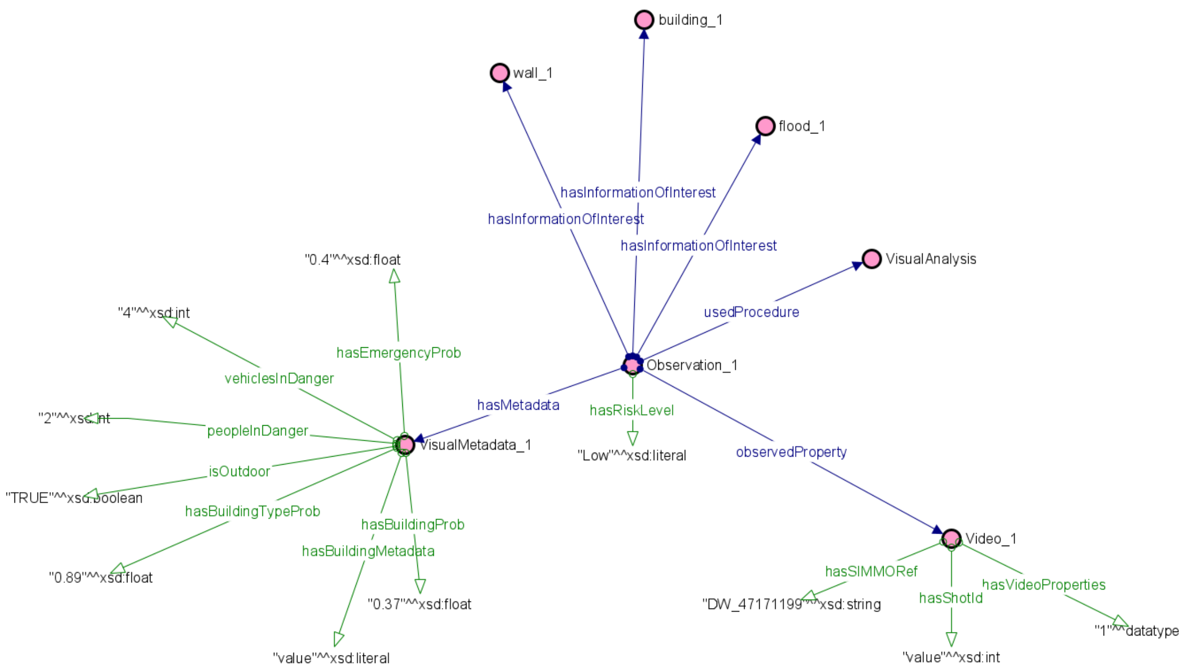

Figure 4-5 Mapped Data from visual analysis individual output

4.2 Implementation

As we mentioned before, the xR4DRAMA ontology is implemented in OWL 2 and we capitalize on its wide adoption, as well as its formal structure and syntax based on DL. The tool that has been operated for the development and deployment of the ontology that we described in the previous subsections are listed in Table 4-1.

Protégé-OWL v5.5.0	An open-source ontology editor and framework for building intelligent systems.
GraphDB	A popular graph database for locally hosting test versions of the ontology and serving queries as a SPARQL endpoint.
yEd Graph Editor	yEd is a general-purpose diagramming program that can be used to draw many different types of diagrams via an intuitive user interface with the addition of a Graphical Framework for OWL Ontologies (Graphoo). Graphoo is an open-source tool that can be used to present the classes, properties and restrictions within OWL ontologies, or sub-sections of them, as clear and easy-to-understand diagrams.
SPARQL	The semantic query language for submitting queries to the ontology and running rules on top of the knowledge base.

Table 4-1 Implementation Tools

4.3 Evaluation

The ontology evaluation theory is a rising field of research in Ontological Engineering that allows one to cope with the problems of assessing an individual ontology from the angle of specific application aspects. The existing methods for evaluating an ontology adopt approaches either automated or semi-automated that focus on:

- Quantitative aspects: e.g., consistency, expandability, sensitiveness.
- Qualitative aspects: e.g., numbers of classes, properties, individuals.

In the work (Brank et al 2006) four basic methodologies for ontology evaluation had been proposed. The main concept for each one of them and an example of their application are:

- Comparing the new ontology to gold standard ontologies of proven quality (Maedche et al 2002).
- Utilizing new ontology in its intended uses and confirm their functionality (Porzel et al 2004).

- Evaluating the interconnection of the new ontology and its source data (Lee B et al 2013).

- Overseeing an evaluation based on pre-defined requirements and standards (Park j et al 2008).

None of the approaches, referred or not, have proved particularly successful nor can guarantee a good ontological framework, in yielding substantial content. Although they aim to establish the parameters of ontology evaluation, they lack the concrete criteria to gauge ontology quality. In addition, their focus on precision and recall would be better served were ontologies assessed via more systematic methodologies.

For the consistency and quality evaluation of the ontology we used OOPS (OntOlogy Pitfall Scanner), an online tool for detecting the most common pitfalls in ontologies (Poveda-Villalon et al 2014). The tool, after analysing the ontology, provides a list with all the pitfalls it detected along with the associated negative consequences, and suggests modifications in order to improve the quality of the ontology. The pitfalls are categorized based on their severity to:

- **Minor**: Which do not cause any critical problems but correcting them will improve the quality of the ontology.
- **Important**: They are quite important and affect the quality of the ontology.
- **Critical**: They are affecting the ontology's consistency and must be corrected.

We submitted the current initial version (v1.0) of the ontology to OOPS. There was no Critical error, and we corrected all the important ones. There are some minor pitfalls around the annotations of the entities in the ontology, but they will be added during the next stage of the project.

For the structural part of the evaluation, we used the OntoMetrics tool, an online framework that evaluates the ontology based on predefined metrics, namely basic and schema metrics. The following tables present the results of the process. Table 4-2 contains the basic metrics that show the quantity of the ontology, numbers of triples, classes, object and datatype properties, individuals, and DL expressivity.

Basic Metric	Value
Axioms	255
Logical axioms count	157
Class count	44
Total classes count	44
Object property count	15
Total object properties count	15
Data property count	29

Total data properties count	29
Properties count	39
DL expressivity	ALCHI(D)

Table 4-2 Ontology's Base metrics

Initially we will comment about the base metrics, the total count of classes and properties of the xR4DRAMA ontology reflects that this version is a lightweight one, which could be easily adopted by various applications, in contrast with other ontological frameworks with vast amounts of confusing interactions. Nonetheless, we have to repeat at this point that there are going to be additions and further enrichment with entities regarding the systems aspects that will be integrated later.

As for the schema metrics we used the methodological framework proposed in OntoQA (Tartir et al 2005) regarding the interpretation of the OntoMetrics results (Table 4-3). The following definitions were adopted:

- **Attribute richness**: the number of attributes that are defined for each class can indicate both the quality of ontology design and the amount of information pertaining to instance data. So, we assume that the more slots that are defined the more knowledge the ontology holds.
- **Inheritance richness**: this measure describes the distribution of information across different levels of the ontology's inheritance tree or the fan-out of parent classes. This is a good indication of how well knowledge is grouped into different categories and subcategories in the ontology.
- **Relationship richness**: this metric reflects the diversity of relations and placement of relations in the ontology. An ontology that contains many relations, other than class-subclass relations, is richer than a taxonomy with only class-subclass relationships.
- **Axiom/Class, Class/Relation, Inverse Relations ratio**: are indications of the ontology's transparency and understandability. Describe the relations between the aforementioned attributes (axioms, class. Relation, etc).

Schema Metric	Value
Attribute richness	0.545455
Inheritance richness	0.75
Relationship richness	0.34
Axiom/class ratio	5.7954
Inverse relations ratio	0.066667
Class/relation ratio	0.88

Table 4-3 Ontology's Schema Metrics

5 Semantic Reasoning for Decision Support

A high-level reasoning architecture is illustrated in Figure 5-1. Briefly, we can say that the reasoning framework extends the xR4DRAMA semantic models to predefined rules that formulated based on the available context (e.g., metadata collected from the analysis results, population of the KB). The semantics are used to acquire an early understanding of the available contents and dependencies among the multimodal results in the form of interlinked data. The knowledge graphs that formed are used as an input to the reasoning tool that triggers the necessary reasoning rules to export additional knowledge. For a better understanding, the reasoning framework can be seen as a schema that combines data integration and interpretation.

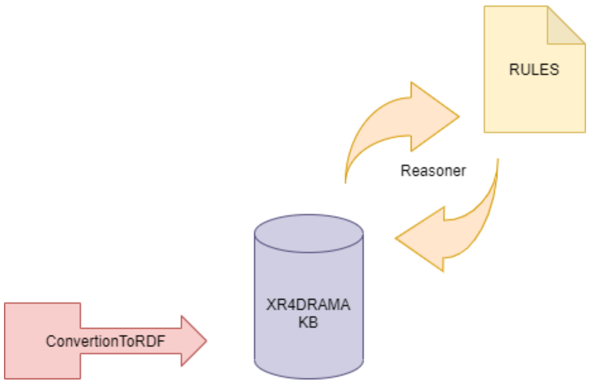

Figure 5-1 High level architecture of Semantic Reasoning

Apart from semantically analysing and correlating metadata, the reasoning framework excels at providing more complex searching capabilities to the end users, elaborating the SPARQL mechanics. This module is still in progress, and it will be further refined and presented in upcoming deliverable. The subsections that follow present some tasks that will be handled by the reasoning framework. The reasoning module is under development, and it will be refined and presented via a later WP3 deliverable, with a more extensive view of the data fusion and clustering. In the following subsections, some basic form of the tasks that can be handled by the reasoning framework, and an introduction to the statistical clustering.

5.1 Discovering Semantic Relations

There is the need to discover links among the heterogeneous data stored in the knowledge base, like audio, video, and social media content. Multimodal clustering on the different types of data will reveal common semantic information among them. For this task to be achieved, two approaches are being considered. First, the usual statistical clustering approach, which is a type of unsupervised learning. To apply statistical clustering on a set of different modalities, the latter need to be aligned, e.g., both audio and video recordings were recorded at the same timestamps. Secondly, semantic clustering approach that will be applied on social media content to discover semantic relations among the different types of information that can be found in e.g., a tweet.

5.1.1 **Statistical clustering**

In this section we describe the first approach of statistical clustering. Clustering is a type of unsupervised classification method. This type of analysis finds common characteristics in a set of observations and assigns the observations to groups according to these common traits (Diday et al 1976). The most popular clustering methods are K-means and hierarchical clustering. K-means groups observations into k clusters. Each cluster comprises of observations with means near the cluster centre. This method reduces the within clusters variances (Hartigan et al 1979). Hierarchical clustering is a method that creates clusters with the top-down or bottom-up approach. In the first approach all cases belong to one cluster and as the recursive algorithm proceeds, they are divided into more (divisive approach) and in the second approach each case forms an individual cluster and as the algorithm proceeds, clusters are merged (agglomerative approach) (Maimon et al 2005). Both clustering techniques require numeric variables.

For mixed types of variables, i.e., numeric and categorical, other types of clustering are available. K-prototypes is an extension of k-means for clustering numeric and categorical data (Huang 1998). K-prototypes combines k-modes, which is the k-means version for categorical data with k-means for clustering numeric data. k-modes creates clusters according to the matching categories of the variables.

In xR4DRAMA, the data stored in KB involve both categorical and numeric results, thus an approach like k-prototypes will be followed. However, it seems more plausible to apply semantic clustering on the text data saved from web-crawling component, to retrieve and organize the multimodal information of social media data. Semantic clustering is used to group web content based on common vocabulary. This approach is found is situation awareness tasks (Kingston et al 2018). Semantic clustering approaches require some initial data cleaning, which involves removal of irrelevant text from the web retrieved content and then semantic trees are created from connected words, which later form the clusters.

5.2 **Rules**

We use SPARQL, to implement expressive reasoning rules, enabling property value propagation and instance generation. The core idea is to associate each reasoning task with one or more SPARQL rules that support specific reasoning functionality, e.g., aggregation of different Risk levels. In the following, we present examples of such reasoning and rules. More elaborate rule-based reasoning cases will be presented in detail in future versions of the framework and reported in upcoming deliverable.

In Figure 5-2 we can see a basic rule that can be applied in the stored data to retrieve a new risk level.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
Delete (?observation :hasRiskLevel ?prev_risk)
Insert (?observation :hasRiskLevel "High")
Where {
        ?observation rdf:type :Observation
        ?metadata rdf:type :VisualMetadata
        ?metadata :peopleInDanger ?people
        ?metadata :emergencyProb  ?emergencyPr
Filter (?people>"2"^^xsd:int && ?emergencyPr>"0.5"^^xsd:float
}
```

Figure 5-2 Sample Rule in SPARQL

The reasoning concepts that we aim to accomplish have as guidelines the following major themes:

- **Risks Aggregation:** The different components have analysis results that can lead to specific risk levels. The visuals from information regarding the entities in dangers and the emergency types. The stress level from the high levels of stressed that are recorded. To have a final Risk Report to send to the authoring tool, we will aggregate information from the metadata in order to produce it.
- **Citizens-To-Project:** The citizens that will be involved during the process of a project won't be able to know anything around it. With the location coordinates that will be retrieved from their reports and the information that these reports will contain we will make an assumption regarding the possible project they will belong so we can use this new knowledge in higher level of analysis.
- **Risk/Safe areas Alerts:** The reasoning engine will support initialization of safe or risk areas with their coordination and a possible description. During an emergency event we will process knowledge from the other components about the availability and the situation of each of the areas respectively and will inform the authoring tool, to proceed with the notification of the citizens and/or first responders.
- **Spacio-Temporal event related Information:** Certain analysis results of the other modules contain either temporal or geolocated information. The reasoning framework will group this kind of information so there can be an overall view of each disastrous event.

6 ONTOLOGY VALIDATION

In this section a xR4DRAMA annotation model is presented in order to map the outcome of the other tasks from WP3. In this regard we took into account a simulation example that was provided by the technical partners responsible from visual, stress and textual analysis. The simulation example was related to generated results that guided us to generate the annotation vocabularies. The following JSON was given as input and accordingly the TURTLE RDF was formed as output

6.1 Visual Analysis Data

The following example was used as an input in the mapping service of the conversion from JSON to RDF based on the ontology that was described in Section 4. The visual analysis module sends its data in the following API knowledge_base/population/{visuals}


```
{
  "header": {
    "timestamp": " 2020-03-24T13:02:08.69",
    "sender": "Visual Analysis",
    "entity": "video",
    "simmoid": "14080373031933309186"
  },
  "shotInfo": [
    {
      "shotIdx": 0,
      "startFrame": "0",
      "endFrame": "203",
      "objectsFound": [
        {
          "type": "wall",
          "probability": 0.56
        },
        {
          "type": "person",
          "probability": 0.82
        }
      ],
      "peopleInDanger": 0,
      "vehiclesInDanger": 0,
      "riverOvertop": false,
      "area": "berth",
      "areaProb": 0.3972055555555555,
      "outdoor": false,
      "emergencyType": "none",
      "emergencyProb": 1
    }
  ]
}
```


The output in the RDF syntax of the information from the previous JSON is given below

```
<!--
http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#Observation
_01 -->
```

```
    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#
Observation_01">
        <rdf:type
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#Observation"/>
        <InitialxR4DRAMA1:hasInformationofInterest
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#InfofInt_01"/>
        <InitialxR4DRAMA1:hasInformationofInterest
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#infofInt_02"/>
        <InitialxR4DRAMA1:hasMetadata
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#VisualMetadata_01"/>
        <InitialxR4DRAMA1:isConsistedIn
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#Project_01"/>
        <InitialxR4DRAMA1:usedProcedure
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#VisualAnalysis_01"/>
        <InitialxR4DRAMA1:hasId
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">01</InitialxR4DRA
MA1:hasId>
        <InitialxR4DRAMA1:hasTime
rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime">2020-03-
24T13:02:08.69</InitialxR4DRAMA1:hasTime>
    </owl:NamedIndividual>

    <!--
http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#Video_01 --
>

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#
Video_01">
        <rdf:type
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#Video"/>
        <InitialxR4DRAMA1:hasSIMMORef
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">14080373031933091
86</InitialxR4DRAMA1:hasSIMMORef>
        <InitialxR4DRAMA1:hasShotldx
rdf:datatype="http://www.w3.org/2001/XMLSchema#int">1</InitialxR4DRAMA1:
hasShotldx>
    </owl:NamedIndividual>



    <!--
http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#VisualAnaly
sis_01 -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#
VisualAnalysis_01">
        <rdf:type
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#VisualAnalysis"/>
```

```
    </owl:NamedIndividual>



    <!--
http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#VisualMetad
ata_01 -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#
VisualMetadata_01">
        <rdf:type
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#VisualMetadata"/>
        <InitialxR4DRAMA1:hasBuildingFound
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">true</InitialxR4
DRAMA1:hasBuildingFound>
        <InitialxR4DRAMA1:hasBuildingProb
rdf:datatype="http://www.w3.org/2001/XMLSchema#float">0.75</InitialxR4DR
AMA1:hasBuildingProb>
        <InitialxR4DRAMA1:hasBuildingTypeProb
rdf:datatype="http://www.w3.org/2001/XMLSchema#float">0.56</InitialxR4DR
AMA1:hasBuildingTypeProb>

<InitialxR4DRAMA1:hasEmergencyProb></InitialxR4DRAMA1:hasEmergencyProb>
        <InitialxR4DRAMA1:hasEmergencyProb
rdf:datatype="http://www.w3.org/2001/XMLSchema#float">1.0</InitialxR4DRA
MA1:hasEmergencyProb>
        <InitialxR4DRAMA1:hasRiverOvertop
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">false</InitialxR
4DRAMA1:hasRiverOvertop>
        <InitialxR4DRAMA1:isOutdoor
rdf:datatype="http://www.w3.org/2001/XMLSchema#boolean">false</InitialxR
4DRAMA1:isOutdoor>
    </owl:NamedIndividual>



    <!--
http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#infofInt_02
-->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#
infofInt_02">
        <InitialxR4DRAMA1:hasProb
rdf:datatype="http://www.w3.org/2001/XMLSchema#decimal">0.82</InitialxR4
DRAMA1:hasProb>
        <InitialxR4DRAMA1:hasType>person</InitialxR4DRAMA1:hasType>
    </owl:NamedIndividual>
</rdf:RDF>
```


6.2 Stress Level Data

As with the visual analysis, we have the stress level output analysis in the form of the following JSON. This module sends its data in the following API knowledge_base/population/{stress}

```
{
  "Latitude": 40.5993542,
  "Longitude": 22.9756221,
  "Probability": "NULL",
  "Stress_Level": "43.47095787525177",
  "Timestamp": "24-11-2021 14:33:39",
  "User_ID": "admin"
}
```


The output in the RDF syntax of the information from the previous JSON is given below


```
<!--
http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#Observation
_02 -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#
Observation_02">
        <rdf:type
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#Observation"/>
        <InitialxR4DRAMA1:hasId
rdf:datatype="http://www.w3.org/2001/XMLSchema#string">02</InitialxR4DRA
MA1:hasId>
        <InitialxR4DRAMA1:hasTime
rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime">2020-03-
24T14:33:39.00</InitialxR4DRAMA1:hasTime>
    </owl:NamedIndividual>
    <rdf:Description>
        <rdf:type
rdf:resource="http://www.w3.org/2002/07/owl#NegativePropertyAssertion"/>
        <owl:sourceIndividual
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#Observation_02"/>
        <owl:assertionProperty
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#hasResult"/>
        <owl:targetIndividual
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#Result_02"/>
    </rdf:Description>
    <rdf:Description>
        <rdf:type
rdf:resource="http://www.w3.org/2002/07/owl#NegativePropertyAssertion"/>
        <owl:sourceIndividual
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#Observation_02"/>
        <owl:assertionProperty
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#isConsistedIn"/>
        <owl:targetIndividual
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#Project_01"/>
    </rdf:Description>
```

```
    <!--
http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#Result_02 -
->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRAMA#
Result_02">
        <rdf:type
rdf:resource="http://www.semanticweb.org/ontologies/2021/5/InitialxR4DRA
MA#Result"/>
        <InitialxR4DRAMA1:hasStreesLevel
rdf:datatype="http://www.w3.org/2001/XMLSchema#float">43.47096</Initialx
R4DRAMA1:hasStreesLevel>
    </owl:NamedIndividual>
```

7 CONCLUSIONS AND FUTURE OUTLOOK

In this document the requirement specifications and the state-of-the-art analysis relevant to the development of the semantic knowledge structures addressed within T3.5 and T3.7 is provided. The status of the xR4DRAMA ontology towards the first prototype is also described. In addition, it was presented the knowledge base population procedure with incoming analyses results from the components of WP3. We also presented a basic structure of the reasoning framework with sample rules for combining, integrating, semantically interpreting, and enriching the knowledge captured in the KB and an introduction to the clustering/fusion subtask.

Next steps for this task that are going to be implemented until M22 include:

1. Extension of the xR4DRAMA ontology, to fully cover the user requirements. Adaptation after receiving new data to cover the PUC 2 scenario.
2. Development of the reasoning framework ruleset, and its service functionality to inform the authoring tool and the users.
3. Integration of advanced reasoning techniques, like fuzzy ontologies or Semantic Complex Event Processing techniques.
4. Capturing and mapping a significant amount of data to facilitate the fusion and clustering tool.
5. Mapping the xR4DRAMA ontology with other models, at the final stage of the development such kind of mappings with external frameworks will establish interoperability. This process includes the formulation of a document that contains the semantic relationships between our concepts with other vocabularies, some of which presented in Section 1.

8 REFERENCES

Baader F. et al. (2003). The description logic handbook: Theory, implementation and applications. Cambridge university press.

Buttigieg P. L., Morrison N., Smith B. et al. (2013). The environment ontology: contextualising biological and biomedical entities. Journal of Biomedical Semantics, 4(43). https://doi.org/10.1186/2041-1480-4-43

Compton M. , Barnaghi P., Bermudez L., García Castro R., Corcho O., Cox S., Graybeal J., Hauswirth M., Henson C., Herzog A., Huang V.,Janowicz K., Kelsey D., Phuoc D., Lefort L., Leggieri M., Neuhaus H., Nikolov A., Page K., Taylor K. (2012). The SSN Ontology of the W3C Semantic Sensor Network Incubator Group. Web Semantics: Science, Services and Agents on the World Wide Web. 17. 10.1016/j.websem.2012.05.003.

Deborah L., McGuinness, F. van H. (2004). Owl web ontology language overview. W3C recommendation 10.2004-03. DOI: https://doi.org/10.1145/1295289.1295290.

Diday, E., & Simon, J. C. (1976). Clustering analysis. In Digital pattern recognition (pp. 47-94). Springer, Berlin, Heidelberg.

Hartigan, J. A., & Wong, M. A. (1979). Algorithm AS 136: A k-means clustering algorithm. Journal of the royal statistical society. series c (applied statistics), 28(1), 100-108.

Hobbs J. R., Pan F. (2004) An Ontology of Time for the Semantic Web. CM Transactions on Asian Language Processing (TALIP): Special issue on Temporal Information Processing. Vol. 3, 1, pp. 66-85.

Hoill Jung and Kyungyong Chung. 2015. Ontology-driven slope modeling for disaster management service. <i>Cluster Computing</i> 18, 2 (June 2015), 677–692. DOI:https://doi.org/10.1007/s10586-015-0424-1

Huang, Z.: Extensions to the k-modes algorithm for clustering large data sets with categorical values, Data Mining and Knowledge Discovery 2(3), pp. 283-304, 1998.

Janowicz,K., Haller, A., Cox.J.D., S., Le Phuoc,D., Lefrançois,M. (2019). "SOSA: A lightweight ontology for sensors, observations, samples, and actuators". Journal of Web Semantics, 56, pp. 1-10. DOI: https://doi.org/10.1016/j.websem.2018.06.003

Kingston, C., Nurse, J. R., Agrafiotis, I., & Milich, A. B. (2018). Using semantic clustering to support situation awareness on Twitter: the case of world views. Human-centric Computing and Information Sciences, 8(1), 1-31.

Knublauch H., Hendler J. A., Idehen K. (2011). SPIN - Overview and Motivation W3C: Member Submission 22 February 2011.

Lee B., Kim H. (2013), “Design and evaluation of an individual instance-based ontology retrieval system for archival records of the ‘Saemaul movement’”, Journal of Korean Society of Archives and Records Management, Vol. 13 No. 3, pp. 67-97.

Maedche A. ,Staab S. (2002), “Measuring similarity between ontologies”, paper presented at *13th International Conference, EKAW,* Sigüenza, October 1-4, available at: www.researchgate.

Maimon, O., & Rokach, L. (Eds.). (2005). Data mining and knowledge discovery handbook.

Masmoudi M., Karray H., Ben Abdallah S., Zghal H., Archimède B. (2019). MEMOn: Modular Environmental Monitoring Ontology to link heterogeneous Earth Observed data. Environmental Modelling & Software. 124. 104581. 10.1016/j.envsoft.2019.104581.

Noy, N. & Mcguinness, Deborah. (2001). Ontology Development 101: A Guide to Creating Your First Ontology. Knowledge Systems Laboratory. 32.

Pan F. ,Hobbs J. R. (2004).Time in OWL-S. Proceedings of the AAAI Spring Symposium on Semantic Web Services. s.l.: Stanford University. pp. 29-36.

Park J., Cho W., Rho S. (2008), “Measurement criteria for ontology extraction tools”, Journal of Intelligent Information Systems, Vol. 14 No. 4, pp. 69-87.

Perez J. et al. (2006). Semantics and Complexity of SPARQL. 30–43. DOI: https://doi.org/10.1145/1567274.1567278.

Porzel R., Malaka R. (2004), “A task-based approach for ontology evaluation”, paper presented at *ECAI Workshop on Ontology Learning and Population*, Valencia

Poveda-Villalón M., Gomez-Perez A., Suárez-Figueroa M. C. (2014). OOPS! (OntOlogy Pitfall Scanner!): An on-line tool for ontology evaluation. International Journal on Semantic Web and Information Systems. 10. 7-34. 10.4018/ijswis.2014040102.

Son, J.; Lim, C.-S.; Shim, H.-S.; Kang, J.-S. Development of Knowledge Graph for Data Management Related to Flooding Disasters Using Open Data. Future Internet 2021, 13, 124. https://doi.org/10.3390/fi13050124

Studer R. et al. (1998). Knowledge engineering: Principles and methods. Data & Knowledge Engineering. 25, 1–2, 161–197. DOI: https://doi.org/10.1016/S0169-023X(97)00056-6.

Suárez-Figueroa M. C., Gómez-Pérez A., Villazón-Terrazas B. (2009). “How to Write and Use the Ontology Requirements Specification Document.” In Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics).

Tartir S., Arpinar I., Moore M., Sheth A., Aleman-Meza B. (2005). OntoQA: Metric-Based Ontology Quality Analysis.