# OMEGAFormat: A Comprehensive Format of Traffic Recordings for Scenario Extraction

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**Abstract:** The most crucial aspects influencing the behavior of Automated Vehicles (AVs) are static environment, dynamic objects and weather. Traffic recordings that include these aspects allow the derivation of comprehensive test scenarios of AVs. However, existing recording descriptions are either not designed for test scenario derivation or use separate formats for the mentioned aspects. Therefore, in this paper, we present an hdf5-based recording format that unifies the data basis for scenario derivation by covering all layers of the 6-Layer Model (6LM). By open-sourcing the format specification along with a library† and converters and enrichers §, we hope to facilitate research on scenario generation considering all relevant aspects of traffic.

**Keywords:** automated driving, environment description, scenario-based validation, traffic recording

## 1 Introduction

For the verification and validation of Automated Driving Function (ADF) the scenario-based approached is favored. Driving randomly in real-world traffic to achieve a safety assurance is not feasible [1]. Therefore, the scenario-based approach focuses on investigation of situations that are in some way challenging for the ADF. To find such scenarios, two methods are known: knowledge-based and data-driven [2]. The format developed in this paper was mostly developed to facilitate the data-driven approach. However, the two approaches are interrelated, meaning that it can also contribute to the knowledge-based approach.

A scenario-based validation and testing workflow was developed in the research project PEGASUS [3]. Different sources of data, such as field test- or naturalistic driving data and data from accident databases, can function as input information [4]. The available data can be stored in a database and subsequently analyzed to derive logical scenarios [5] and transform those into sets of test cases. The format developed in this work comes into play at the beginning of the workflow when gathering data. A wide variety of input data sources are possible. However, those data sources all provide different information

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†Format and library: `https://github.com/ika-rwth-aachen/omega_format/tree/master/omega_format`.

§Data converters: `www.github.com/ika-rwth-aachen/vvm-rec-converters`.

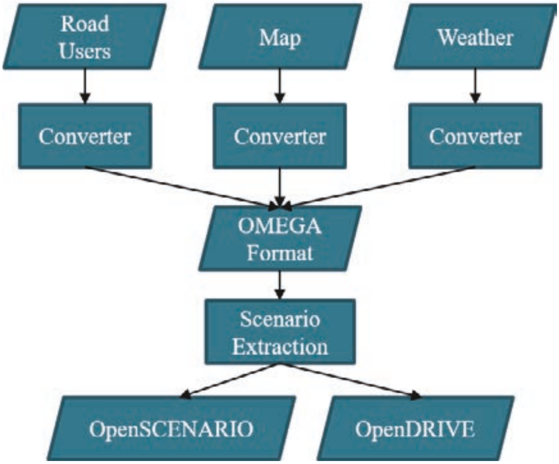


Figure 1: The OMEGA format harmonizes the data representation of traffic recordings such that approaches for scenario extraction can rely on this defined input format.

in different formats. In order to establish a uniform data processing chain, a harmonized data format is needed [4].

Currently the existing formats and data as well as the processing algorithms and concepts mostly consider information on road users [6] [7]. To the best of the knowledge of the authors, there is no format available that covers all six layers of the 6LM for environment description [8]. The model is commonly used to provide a structured description and categorization of the complex and open real-world design domain. The format developed in this work is not only important in terms of harmonization, but also due to it covering all six layers of the 6LM. This is essential since relevant scenarios that need to be considered in the validation process can also be triggered through properties of the road network [9] or weather data.

The latter is also of utmost interest when assessing perception data gathered by an ADF [10]. The traffic data recorded can not only be used as an input source for the scenario-based approach focusing on planning and acting of an ADF, but also as reference data that can be compared to recorded perception/sensor data.

Our contributions in this paper are:

- We propose an open data format including tooling that systematically covers all six environment description layers [8]. –> Section 3.2, 3.3, 3.4 and 3.5
- We provide research on the entities relevant for description and data analysis. At the same time, the goal is that those factors stay retrievable. Furthermore, common classifications of factors are provided. This is also of use for knowledge-based scenario approaches that focus on ontology creation [11]. –> Section 3

- The format stays compatible with existing formats that only cover certain aspects of the 6LM. There are converters from other formats into our holistic format available. –> Section 4
- The format provides a clever inclusion of temporary aspects in the map description. Therefore, it can be easily reused for recordings at the same locations even if temporary aspects are present. –> Section 3.2
- Our format provides a description through polylines that stays understandable, interpretable and is flexible. For instance, repeating objects can be easily described without having to provide information on each individual object. –> Section 3.1 and 3.2
- We introduce one consistent time stamp for easy comparison. This is especially handy when using the proposed format in combination with perception recordings. –> Section 3.1 and 6

## 2 Related Work & Methods

In general, there is a wide variety of different data containers and encodings available. They were developed for different use cases such as pure data exchange or semantic recording and feature different compression rates. Some formats, also used in the automotive context, are .csv, .mat, .json, .xml, .hdf5 or rosbags. In [12], a more detailed analysis of different file formats can be found.

Various existing formats addressing individual layers of the 6LM were analyzed during the development of the OMEGA format. In the automotive context, divers partly standardized formats exist that use the different data containers. Coming from the area of simulation, the formats OpenDRIVE [13] and OpenSCENARIO [14] are used that are both based on an xml schema. Furthermore, Lanelet2 [15] is a map format often used in the scientific context for trajectory planning of an ADF. All the different formats require different libraries and tools to view them. Some of which are not free even though the formats are generally open source. Other research projects like PEGASUS [3] and L3Pilot [12] have developed their own formats to save traffic recordings in the .mat or .hdf5 schema. However, those formats were developed with the use case highway in mind and mostly focus on road user information. The aim of the format described in this work is to cover all layers of the 6LM.

To meet this requirement also existing taxonomies and ontology schemas for ADF were studied. Those feature schemas to describe the real-world conceptually rather than through data. For this work specifically a taxonomy by NHTSA [16] and a world model ontology were analyzed [17], [18].

The developed OMEGA format is designed to be applicable for different modes of data recording. Traffic recordings can for instance be acquired by a sensor equipped vehicle or infrastructure or through drones. The OMEGA format can be used for the different data sources or a fusion of such [19]. This facilitates the processing of the different data sources to extract scenarios and implement a validation process for ADFs.

# 3 The OMEGA Format

The OMEGA data format uses the hdf5 format [20] to store the data. The hdf5 data model utilizes *groups* and *datasets* to store data objects. Furthermore, attributes are used to describe certain objects to which they are attached. They contain metadata of those objects. The documentation available at [21] provides further information how the individual signals are stored. In general, the hdf5 file format was chosen as it proved to be useful in other public research projects [12]. The main advantage of the format is its portability across different platforms. The format can be used in different programming languages such as Python or C++ and is also supported by newer versions of MATLAB. Investigations regarding the memory consumption and achievable compression can be found in [12].

Section 2 has introduced different formats currently used in the area of validation and verification for ADFs. Those formats usually depict only certain aspects of the 6LM [8]. For instance, formats like OpenDRIVE or Lanelet2 concentrate on the description of the road network (Layers 1 to 3) while OpenSCENARIO depicts dynamic information (Layers 4 to 6). The format introduced at hand aims at addressing all layers of the 6LM in one format with one consistent time stamp (see Section 3.1). Furthermore, data campaigns in larger research projects with different entities tend to produce several different recording formats. For the analysis, however, it is very useful to establish one format. Obviously, when deriving the format, it should be considered which signals and information are needed for the applications planed so that all of those can be retrieved by all entities recording data. However, when designing the format at hand, it was also considered which signals are retrievable in some way in the first place, since some information might be nice to have, but impossible to gather without large efforts.

The following sections will give an overview on the different signals used in the format. For extensive details and technical information the reader is referred to the Github repository [21] and its corresponding documentation.

## 3.1 Basics

At the top level, the format contains some descriptive meta information in form of hdf5 attributes. Those information lets the user know which format version the file is in and which partner recorded the data at which time of the day (e.g. needed to enrich weather information). Furthermore, a unique recording number is set. This is helpful to link the data to other information such as perception data also captured during the recording (see Sec. 6 for more details) or reference videos. In contrast to formats used in PEGASUS or L3Pilot, which are designed for highway applications, the format at hand uses an absolute coordinate system. This has the clear advantage that no predefined ego vehicle is existent. It can be imagined as a birds eye perspective, such as received by using drones [6]. The absolute coordinate system is located at a certain point given in lateral and longitudinal coordinates. The information on this point is also provided in the top-level attributes. All positional information is given relatively in respect to that point. This is legit as the format is designed mainly for urban applications, such as recordings at an intersection, and not for hundreds of kilometers along a highway. Furthermore, for later analysis purposes, it is important to know if the recording features natural behavior of all traffic

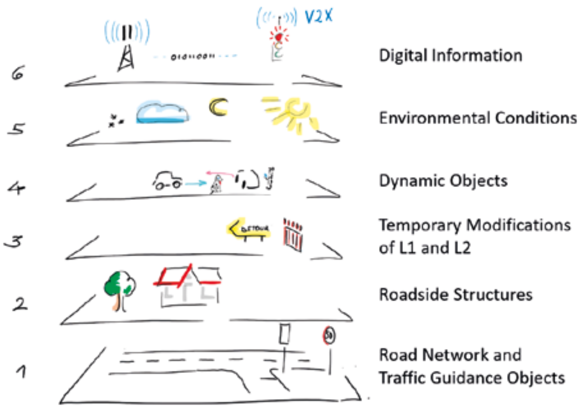


Figure 2: Different layers of the 6LM also covered in the format of this work.

participants (i.e. is not staged) and natural exposure (i.e. no preselection has been made on the basis of various criteria before providing the data). This information is also stored in the attributes.

One special characteristic of the format is the synchronized time stamp for all recorded time-dependent data. All data that is to be recorded in the format and consists of a time series, such as trajectory data of an object or weather data, uses the same time stamp vector that is contained in the format only once. I.e., the xth entry in the object information, such as longitudinal position, corresponds to the xth entry in the time stamp vector. This enables synchrony of the data already by design.

In general, the format uses so called polylines, i.e. a set of different points with x, y and z coordinates, to describe the road outline, trajectories, etc. This is in contrast to the design chosen in OpenDRIVE which uses euler spirals, etc., but is better suited for the use case. Polylines can easily be extracted from real world data, which is the primary use case of this format and for which already fitted spirals, and polynomials are not given. Above all, it stays easily readable and also complex shapes, e.g., for different buildings, can be described by a polygon course.

In the following, the information is structured by the different layers of the 6LM. Since map data, information on dynamic objects and weather data usually comes from different sources, separate fields are provided to note down the version of the corresponding converters used. This allows for traceability if changes are made to a certain converter used by a certain data provider.

## 3.2 Map Data (Layers 1,2,3 of the 6LM)

The map data includes information that is static for the duration of the recording. This comprises the road network and traffic regulating objects as well as roadside structures (Layer 1 and 2 of the 6LM). Furthermore, the elements described here can experience temporary changes (Layer 3 of the 6LM), such as during road work. In such cases, existing information can be flexibly modified and new elements can be added noting that they are temporary. This is advantageous if generating several recordings at the same intersection with road work being present for some of those recordings. The existing road description can stay unaltered with the temporary modifications being stacked on top. All information on Layer 1 to 3 entities of the 6LM is included in the *road* group of the format.

Wherever possible, the format sticks to existing norms of road construction [22] to simplify the description. Furthermore, it uses official type catalogs, such as the traffic sign catalog of the Bundesanstalt für Straßenwesen (BASt) [23]. Nevertheless, for some signals, such as condition of the road surface or marking, human judgment needs to be applied.

For some repetitive and extended structures, the format decreases the complexity of their description by providing specific boundary types. For instance, guard rails or reflector posts do not need to be modeled separately, but the boundary type of a lane can be set to the specific type. If the type is present, it is assumed that the corresponding element is extended along the lane without describing each entity individually. Furthermore, to decrease the complexity even further, the format separates the description of the geometrical border of a lane and its actual boundary type. This allows for the use of several boundaries. Therefore, a lane can feature a solid lane marking and a guard rail without having to describe these via separate lanes.

The map data of the format is compatible to OpenDRIVE and Lanelet2, but is more closely orientated towards Lanelet2. For instance, the lanes of a road are described via polylines that depict their borders rather than using one center line, center line offsets and lane widths such as in OpenDRIVE. Each road in the format at hand features borders, signs, lateral markings (e.g. stop line), road objects (e.g. a traffic island), structural objects (e.g. a building) and lanes. The lanes themselves then contain information on their boundary, flat markings (pictograms such as a bicycle sign) and their surface. Since the variety of structural objects that can be encountered in an urban setting can be enormous, the format currently sticks to the most common urban objects and to objects that are expected to impose challenges on the ADF (see also Sec. 6). However, it is generally possible to extend the format and describe all structures using polygon courses.

## 3.3 Dynamic Objects (Layer 4 of the 6LM)

The hdf5 groups *roadUser* and *miscObject* contain information on the dynamic objects (Layer 4 of the 6LM) that are generally able to move (even though they do not necessarily have to). It needs to be stressed that the format does not only concentrate on road users, but also on miscellaneous objects, such as animals, play equipment, etc.

In general, each road user or misc object features a type and a subtype, trajectory data containing position, velocity, etc. for the different time stamps and information on its bounding box. In case the data is recorded by one of the road users, e.g., in case of a measurement vehicle recording reference and/or sensor data, this can also be set as a flag for the corresponding object. The flag will be very important for later analysis, especially if sensor data was recorded along with the traffic recording (see also Sec. 6).

The number of different road user types can be very massive. For the individual road user types, the format sticks closely to the ones chosen in the nuscenes dataset [24] including a few simplifications and adaptations. The classifications are chosen in such a way that they are reasonable and support later data evaluation. Again, for details the reader is referred to the Github repository [21] and its documentation, however, some important aspects are pointed out here. In general, all objects that are coupled, but move individually, such as trailers and pulling entities, are described individually in order for the bounding boxes to be correct in case of turning maneuvers, etc. Furthermore, subtypes that can be provided for the different types of road users are of interest. In general, each road user type can be assigned the subtype *emergency* or *construction*. Choosing this procedure, a car as well as a pedestrian can be marked as a first responder (e.g. police car and police officer) without having to introduce this individually for all types. Moreover, ridable objects such as bicycles, motorcycles and all kinds of personal mobility devices can be equipped with a subtype noting if the object has a rider or not. This can be helpful in the subsequent analysis to differentiate between parked ridable objects and such in use.

### 3.4 Environmental Data (Layer 5 of the 6LM)

All environmental data, weather data and weather related road conditions, are contained in the hdf5 group *weather* of the format. Such data can generally either be measured at time of recording or can be enriched at a later point in time. Each weather signal contained in the format includes a *source* information. In case of later enrichment, the Climate Data Center of the Deutscher Wetterdienst (DWD) [25] can be useful. It provides various weather information in different update intervals reaching from once per minute (precipitation) to once per hour. The format uses the same consistent time stamp described above and covers precipitation information, visibility, cloudiness, solar information, temperature, wind, air pressure and humidity as well as weather related road conditions. For the latter research results of countries/regions with more extreme weather were used [26]. Besides noting down the actual amount of a weather entity, such as precipitation amount or wind speed, also a classification is made. The classifications are based on existing scales [27] and weather warning stages [28].

### 3.5 Status of Traffic Guidance Objects (Layer 6 of the 6LM)

Layer 6 of the 6LM focuses on communication and cooperation aspects on the basis of digital data. It is expected to increase in importance with more propagated implementation of Vehicle-to-Vehicle (V2V) and Vehicle-to-Everything (V2X) concepts [29]. Layer 6 information for the format at hand comprises the status of traffic lights and switchable traffic signs. Note that the position and type of a traffic light / switchable sign is part of the map data (Layer 1). Only the time variable status of such signs is depicted here. Furthermore, the format covers the status of flashing lights or barriers, etc., if desired. Again, the holistic time stamp vector is used.

## 4 Using the format

The published library on Github [21] does not only provide the format and documentation on the choice of signals themselves, but also the complete data structure in Python and C++. This allows to easily read and write the corresponding hdf5 files. Furthermore, enums are provided for the different types allowing for an easy mapping. Along with those functionalities comes a tool to visualize the data in the OMEGA format. For an easier analysis and visualization of large recordings, recordings can be separated into individual snippets featuring the different road users as ego vehicle. The visualizer reveals information on all different layers of the 6LM contained in the OMEGA format. I.e., it can also be used to visualize a specific road network and its regulatory elements. Moreover, the data in the OMEGA format can be verified and sanity checks are provided

The library is published under MIT license that is available in the repository. Adaptations to the format can be made and we encourage users to provide adaptations that could be useful for others via merge requests.

Furthermore, various converters exist to convert existing data into the OMEGA format and use its functionalities. This is the case for OpenDRIVE, Lanelet2 and data from the inD dataset [6]. Additionally, the data can be enriched with weather data from the Climate Data Center of the Deutsche Wetterdienst [25]. Moreover, data from different input sources can be merged together into one OMEGA file.

# 5 Discussion

As stated above, the format covers all layers of the 6LM for environment description and is, therefore, of great value for the tool chain of scenario-based testing. The level of detail is chosen in such a way that the information should stay retrievable either at time of measurement or through data enrichment. However, depending on the recording method chosen, some signals might not be retrievable even though they would be useful for the analysis. Moreover, it needs to be kept in mind that the format and its choice of coordinate system is designed for the use in urban surroundings, e.g., at intersections. It would be usable, but is not designed for locally extended drives, such as, for instance, on a highway. Furthermore, the enrichment of the map data with traffic signs and markings, etc. as well as the status of the traffic lights often requires manual labor or even an additional observer at time of recording. Due to the format being developed in a German research project, it is currently designed for German roads. While it is extendable to other countries, this would require some major updates in terms of classification of the different signals.

We are aware that, through the choice of polylines, depending on the step size, e.g., map data is not as exact as it can be when using the OpenDRIVE format. However, focusing on real world data, extracting polylines has the benefit that they are always available and the format is purposely designed in such a way to simplify the description. A simplification is for instance also achieved when describing reoccurring objects like reflector posts or lanes that feature two boundaries (e.g. gurad rail and solid line). The format and the signals that are depicted in it are under continuous development and are, therefore, still undergoing changes to improve the format. The user should be aware of this when using the format. Updates will be provided with change logs and compatibility should be given.

# 6 Conclusion & Future Work

The format is currently used in a processing chain for validation of ADFs that is under development. The processing chain implements the data-driven scenario approach and gathers traffic recordings from multiple input sources in the harmonized OMEGA format in a database. The metrics applied in the database provide a scenario extraction that detects different scenario types [7]. The concept aims at deriving logical scenarios that can subsequently be transformed into test cases. Those can, e.g, be provided in OpenX formats for the later use in simulation. The input provided by the OMEGA format is also utilized to detect scenario semantics via so called General Descriptive Entity Attributes (GDEAs). This, e.g., includes the detection of parsing events or occlusions.

Furthermore, for the analysis of perception / sensor data a coordinated approach is chosen. Currently a format is under development to cover perception data from different sensor modalities. Through the concerted approach, the recordings in the OMEGA format can be used as reference data and can be compared to the synchronized perception data. This extents the chosen approach for scenario-based safety assurance to perception information, which is a challenging future topic of concern.

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