LINE AND POLYGON TOPOLOGY IN OPENDRIVE MODELLING

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Mobile Mapping Technologies and HD Maps

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ABSTRACT:

The paper discusses the importance of efficient methods in the automotive industry for the development of self-driving vehicles and advanced vehicle assistants, focusing on the use of high-definition (HD) maps. The integration of computer simulation and HD maps in the OpenDRIVE format is emphasized. A paradigm shift in map topology is highlighted, requiring a new map creation and usage approach. The article presents a methodology that addresses both geometric and topological aspects in creating accurate HD map models. The method focuses on the connection of linear and arc road elements and eliminating continuity/connectivity errors in lane descriptions. Real-world tests validate the implemented methodology and demonstrate the successful generation of topologically correct HD map models. The results show the potential of these models for various automotive applications, particularly in the development and testing of self-driving vehicles and advanced vehicle assistants. The methodology contributes to the advancement of HD map creation, providing valuable insights for researchers and map makers in the automotive industry.

INTRODUCTION

The development of self-driving vehicles and advanced vehicle assistants requires efficient methods from the automotive industry. One such method is computer simulation, which has now been expanded to include map content. High-definition maps (HD maps) in simulators are usually provided by specialized service providers in the OpenDRIVE format maintained by ASAM. The current version of the OpenDRIVE standard, version 1.7, regulates in detail the description of not only roads but also lanes [ASAM e.V., 2023].

With the advent of high-resolution maps, it is not just that the maps for vehicles are prepared with greater detail and accuracy. Still, in many ways, a completely new approach is needed when using them, as well as during their preparation. Such a paradigm shift can also be observed in relation to map topology. The previously widespread and commonly used car maps, and later the databases of navigation systems, depicted the road network as a network of linear elements. This meant, for example, that a road could be specified with a list of points on its axis line. When roads meet, and intersections are described, only the connection of the network's lines without gaps or overlaps is an expected condition concerning the topology. In other words, by eliminating under and overshoots, practically the correct topology was achieved.

On the other hand, the novelty of the HD-maps is, among other things, the description of the lanes. However, with the introduction of the lanes, in addition to the increase in the amount of geometric data, it is also necessary to rethink the topological relationships. Effective lane models are created when they can be seen as a generalization of the road network. The creators of OpenDRIVE solved this by providing both road and lane descriptions in the standard: to specify the roads, their reference must be defined, and then the extent of the lanes can be specified geometrically in relation to this reference. The topology appears both at the level of the reference elements and the descriptive data of the lanes. OpenDRIVE assigns both the roads and the lanes with a unique identifier, and then when specifying the individual connections, the topological connections are established by specifying the predecessors and successors - at both levels. At multiple connection locations, i.e., intersections or junctions, an obvious description can be achieved by parameterizing a particular junction element [ASAM e.V., 2023]. The standard only ensures the parameterization of the elements; it does not guarantee its verification or repair. This is the task and responsibility of the map maker. In our article, we study the question of how it is possible to create a perfect model by taking into account the geometric and topological aspects simultaneously. After presenting our theoretical considerations, we describe our procedure implemented during software development and demonstrate the operation of the procedure using a synthetic example.

METHODOLOGY

Models describing the reality created for simulations are built from several basic elements. The primitives that can be used in OpenDRIVE are line, arc, spiral (clothoid), cubic polynomial, and parametric cubic polynomial. By connecting them, the continuous path and then their network is formed. Among the primitives, the simple third-order polynomial is getting obsolete, so we ignore it. The basic cases of a possible connection of primitives are shown in the following diagram (Fig. 1).

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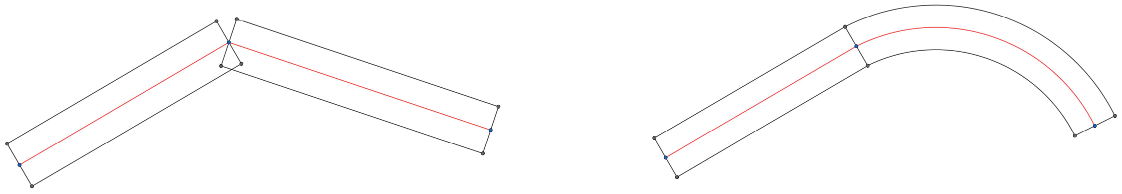

a) Line - Line

b) Line - Arc

c) Arc – Arc (curvature in the same direction)

d) Arc – Arc (curvature in the opposite direction)

Figure 1. Joins of construction primitives in OpenDRIVE

As can be seen in the case of arcs and other non-straight shapes, two adjacent elements can be connected along curves in the same or opposite directions. We limit our investigations to the line-line connection, through which we present the geometric-topological approach. (We intend to deal with the other cases more deeply in a future study.)

According to previous map-making regulations, the lines making up the map consisted of the above elements; they describe the reference axes of the roads in geometric terms. Topologically, a gap-free connection is required for these elements; that is, the endpoint of one element must coincide with the starting point of the next element. We can extend this philosophy to HD maps: we make precisely the same requirement when specifying road reference lines. With the considerations of the lanes, surface objects are created, which already have overlaps and gaps. These continuity errors are wrong not only in a geometrical sense but also in a topological sense; that is, they must be eliminated.

Fig. 2 shows that, in the case of different bandwidths, the two mentioned anomalies may be eliminated with a GIS approach by intersecting the band boundaries. Still, the perpendicularity to the reference is damaged, so this cannot be used with the OpenDRIVE standard.

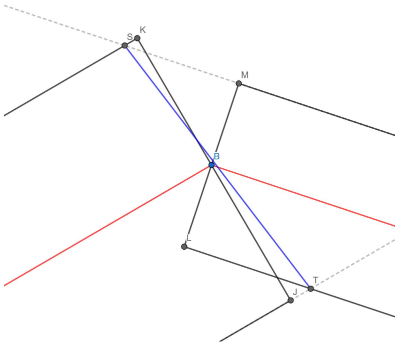

Figure 2. Roads merging by extending the two adjacent road boundaries

The problem can be observed even with the same bandwidth (Fig. 3). Then, calculated ST corner points are needed instead of IJ and KL corner points. However, the standard does not specify the line of the edges of the lanes, but the bandwidth relative to the reference line, so this solution cannot be applied.

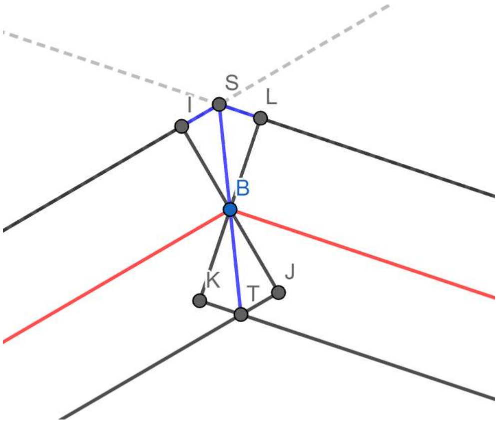

Figure 3. Extending lane boundaries of roads with the same lane widths

In principle, rounding would be a solution, but unfortunately, only with some editing considerations. If we apply the rounding according to Fig. 4, the ILT circular sector can be edited in a CAD system. The geometry is thus acceptable, but in a topological sense, we did not solve the problem of overlaps because we still created an overlapping element with the connecting straight paths: due to the triangles IJT and KLT.

Editing with the outer arc center S shows an even better result, but the topology of this approach is also perfect because the rectangles ZIJV and UKLW fall in the same area as the circle SZW (Fig. 5).

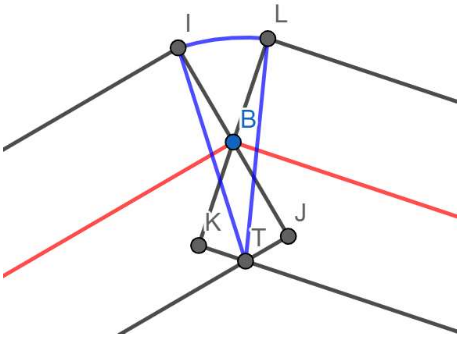

Figure 4. Insertion of an arc
(center on lane boundary intersection)

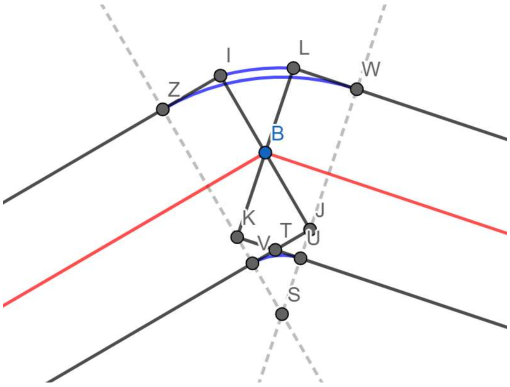

Figure 5. Insertion of an arc
(outer center)

The geometrical situation created with the above process results in a topologically correct model with the inclusion of an additional editing step. This further step can be seen in Fig. 6: the two connecting straight roads (their lanes) must be truncated. In this case, the ZV corner points are needed instead of the IJ corner points, and instead of the KL corner points, the UW corner points are required. Since these points are not specified according to the standard, they are only calculated during the display, so instead of the common point B of the reference lines, points A_1 and B_1 must be introduced. The cut would damage the continuity of the reference of the roads, but it can be corrected with the insertion of an arc. The starting point of the arc's reference is point B_1. This arc can be specified with adequate parametrization in OpenDRIVE so that it is exactly connected to the other straight road section: in addition to the starting point, the radius of the arc (B_1S distance), the direction of its starting tangent and the length of the arc (B_1A_1) must be specified. It can be seen that the editing is unique (unambiguous), as with corner points K and J near the S center of the arc, the locations of the line truncations are clear, thus the position and size of the arc.

In addition to this geometric editing, it is also necessary to assign the appropriate road and lane identifiers to create the topology. Our procedure presented at the theoretical level is thus shown in Fig. 7, which offers a visible layout. Predecessors and successors are as follows:

Road level	**Predecessor**	**Successor**
Road1	—	Road2
Road2	Road1	Road3
Road3	Road2	—

Lane level	**Predecessor**	**Successor**
1 (Road1)	—	1 (Road2)
-1 (Road1)	—	-1 (Road2)
1 (Road2)	1 (Road1)	1 (Road3)
-1 (Road2)	-1 (Road1)	-1(Road3)
1 (Road3)	1 (Road2)	—
-1 (Road3)	-1 (Road2)	—

The topology created at the lane level partly inherits the topology existing at the road level. Unfortunately, this is only true in this simple case, where the paths can be considered as continuations of each other - in our example, moving from left to right. The topological connections of the different cases must be set according to more complicated rules – our previous study provided a collection of procedures for their verification [Lógó-Barsi].

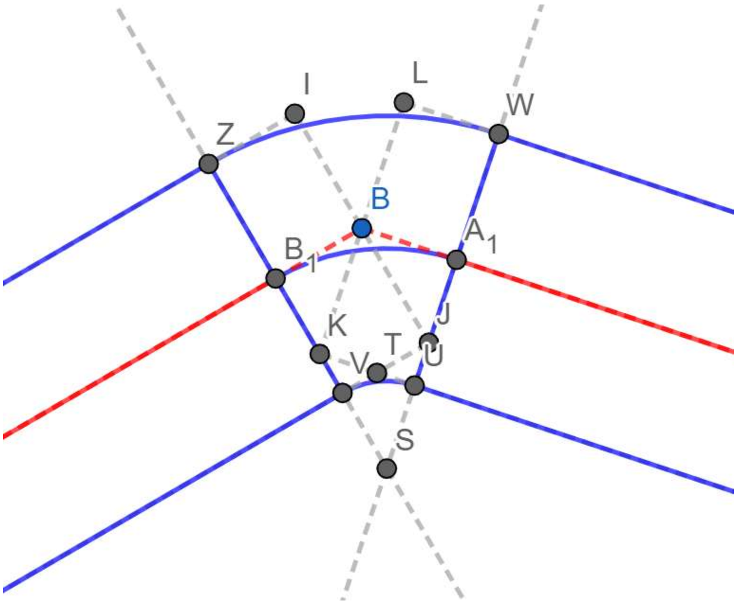

Figure 6. Valid topology and geometry in an OpenDRIVE model

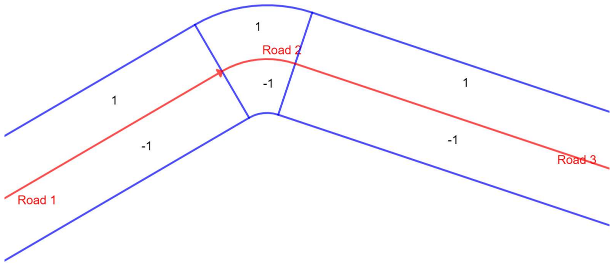

Figure 7. Road and lane topology with identifiers

We implemented the following process in the software development. In the first step, the curve turning to the right or to the left must be decided with the help of a test that examines the location of the endpoint of the connector line compared to the straight road section. The successive road sections are broken at their connection points by the numerical solution of geometric editing described above, i.e., the new reference endpoints and the arc parameters are determined. The left turn case can also be seen from the above. After computing the geometric data, an arc reference element is inserted between the existing straight lines. Then the XML tags are uploaded according to the presented rules to ensure the correct topology. The produced model already shows accurate geometric-topological relations at the same time.

RESULTS

The methodology was implemented in the Mathworks Matlab R2022b environment, while the Mathworks RoadRunner R2022b modeling environment was used for professional visualization and further simulation studies.

The geometric skeleton consists only of straight lines between which arcs have been defined according to the presented automatic calculation method.

Using the developed methodology, we performed tests in a real environment. For the investigation, we chose a road section in Budapest, of which a high-resolution (GSD ~8 cm) orthophoto was available (Fig. 8).

Based on the orthophoto [https://terinfo.ujbuda.hu/], we identified the axes of the road, then digitized them and loaded the coordinates of the breakpoints into the developed software. For quick examination, we have also displayed the geometric skeleton (Fig. 9).

Figure 8. Pilot road segment in orthophoto in Budapest

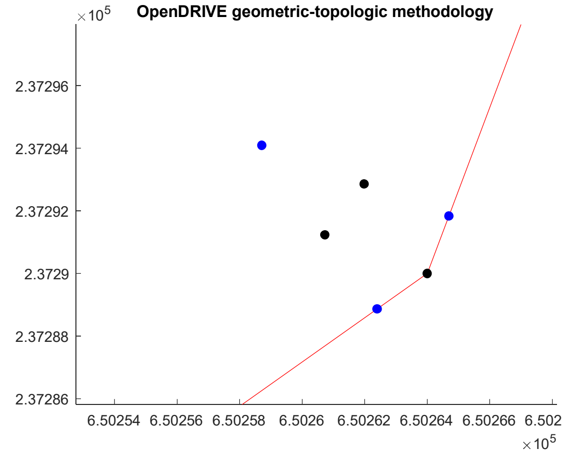

Figure 9. A detail of the geometric skeleton of the pilot road

In modeling the road section, we created a simplified version, which only has 1+1 traffic lanes relative to the road axis. We also used a simplified lane geometry in the modeling: all traffic lanes are equally 3.5 m wide. The developed software then created a xodr model compatible with ASAM OpenDRIVE version 1.7 standard, which was read into RoadRunner and checked. The XML-format description with the tags of the presented model detail amounted to about 140 lines.

Since the model is correct, we added vehicles to the model to demonstrate its future use so that the simulation can also be run (Fig. 10). In our work, we created a model of the roadway, so we did not want to add additional environmental elements (such as buildings, vegetation, traffic signs, etc.) to the model.

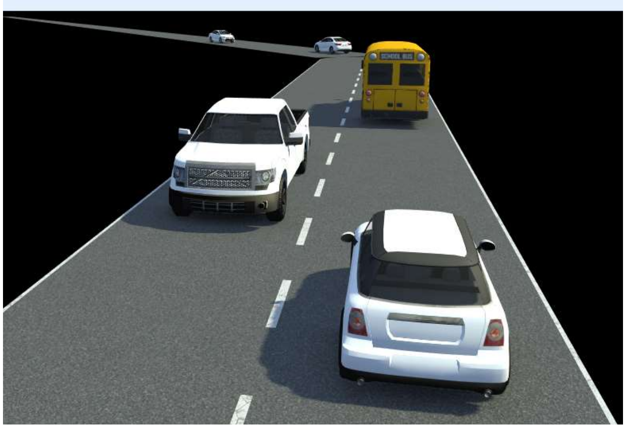

Figure 10. Simulation scenario built in RoadRunner after importing the OpenDRIVE model

CONCLUSION

The paper discusses the utilization of high-definition (HD) maps in the automotive industry, particularly in the context of self-driving vehicles and advanced vehicle assistants. It emphasizes the need for efficient methods, especially before the computer simulation and the adoption of the OpenDRIVE format for integrating HD maps. The advent of HD maps has necessitated a paradigm shift in map topology, demanding a new approach to their creation and usage. The article presents a comprehensive methodology that prioritizes geometric and topological aspects in developing accurate HD map models.

By addressing the potential connection of linear road elements by arcs and, therefore, the elimination of continuity/connectivity errors in lane descriptions, the methodology provides a robust framework for creating accurate HD map models. Then the importance of considering both the geometric and topological relationships between road segments and lanes is highlighted, ensuring a comprehensive and cohesive representation of the road network. It further explores the implementation of the methodology, demonstrating its effectiveness through real-world tests and validations.

The results of the implemented methodology prove the successful generation of topologically correct HD map models. These models hold great promise for various automotive applications, particularly in the development and testing of self-driving vehicles and advanced vehicle assistants. The integration of accurate geometric and topological data enables the realistic and reliable simulations, contributing to the advancement and optimization of autonomous driving technologies.

This research work contributes valuable results in the development and validation of HD maps, and thereby their crucial role in the automotive industry. The presented methodology serves as a valuable resource for map makers and researchers involved in the creation and utilization of HD maps for autonomous vehicles, facilitating advancements in the field and paving the way for safer and more efficient transportation systems of the future.

REFERENCES

ASAM e.V., 2023. ASAM OpenDRIVE® [WWW Document]. URL https://www.asam.net/standards/detail/opendrive/ (accessed 4.25.23).

J. M. Lógó and Á. Barsi, “THE ROLE OF TOPOLOGY IN HIGH-DEFINITION MAPS FOR AUTONOMOUS DRIVING,” Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci., vol. XLIII-B4-2, no. B4-2022, pp. 383–388, Jun. 2022.

MathWorks, n.d. RoadRunner - MATLAB & Simulink [WWW Document]. URL https://www.mathworks.com/products/roadrunner.html (accessed 4.2.22a).

https://terinfo.ujbuda.hu/ (accessed 5.12.23)

Barsi, A., Csepinszky, A., Krausz, N., Neuberger, H., Poto, V., Tihanyi, V., 2019. Environmental data delivery for automotive simulations by laser scanning. ISPRS - Int. Arch. Photogramm. Remote Sens. Spat. Inf. Sci. XLII-2/W16, 41–45. https://doi.org/10.5194/isprs-archives-XLII-2-W16-41-2019

Burg, M., 2019. Simulation as Tool.

Horváth, M.T., Lu, Q., Tettamanti, T., Török, Á., Szalay, Z., 2019. Vehicle-In-The-Loop (VIL) and Scenario-In-The-Loop (SCIL) Automotive Simulation Concepts from the Perspectives of Traffic Simulation and Traffic Control. Transp. Telecommun. J. 20.

CarMaker | IPG Automotive [WWW Document], n.d. URL https://ipg-automotive.com/products-services/simulation-software/carmaker/ (accessed 9.26.19).

HERE, 2018. HD Maps for Autonomous Driving and Driver Assistance | HERE [WWW Document]. URL https://www.here.com/products/automotive/hd-maps (accessed 12.8.19).

Potó, V., Somogyi, J.Á., Lovas, T., Barsi, A., Tihanyi, V., Szalay, Z., 2017. Creating HD map for autonomous vehicles - a pilot study, in: 34th International Colloquium on Advanced Manufacturing and Repairing Technologies in Vehicle Industry. pp. 127–130.

Pai, H.-Y., Zeng, J.-C., Tsai, M.-L., Cheng, K.-W., 2022. Automated Modeling of Road for High-Defintion Maps, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII-B1-2022, 263-270

Diaz-Diaz, A., Ocana, M., Llamazares, A., Gomez-Huelamo, C., Revenga, P., Bergasa, L.M., 2022. HD maps: Exploiting OpenDRIVE potential for Path Planning and Map Monitoring, IEEE Intelligent Vehicles Symposium IV

Barsi, M., Barsi, A. 2021. Building OpenDRIVE Model from Mobile Mapping Data, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLIII-B4-2021, 9-14

Zhou, Y., Takeda, Y., Tomizuka, M., Zhan, W., 2021. Automatic Construction of Lane-level HD Maps for Urban Scenes, IEEE International Conference on Intelligent Robots and Systems (IROS),

Kim, C., Cho, S., Sunwoo, M., Jo, K., 2018. Crowd-Sourced Mapping of New Feature Layer for High-Definition Map, Sensors, Vol. 18, No. 12, 4172

Li, Z., Wegner, J.D., Lucchi, A., 2019. Topological Map Extraction From Overhead Images, IEEE International Conference on Computer Vision (ICCV),

Liu, R., Wang, J., Zhang, B., 2019. High Definition Map for Automated Driving: Overview and Analysis, Journal of Navigation, Vol. 73, No. 12, 324-341

Jang, W., An, J., Lee, S., Cho, M., Sun, M., Kim, E., 2018. Road Lane Semantic Segmentation for High Definition Map, IEEE Intelligent Vehicles Symposium (IV),

M. Dupuis, M. Strobl, Hans Grezlikowski: OpenDRIVE 2010 and Beyond -Status and future of the de facto standard for the description of road networks

Althoff, M., Urban, S., Koschi, M., 2018. Automatic Conversion of Road Networks from OpenDRIVE to Lanelets, IEEE International Conference on Service Operations and Logistics, and Informatics (SOLI),

Ort, T., Walls, J.M., Parkison, S.A., Gilitschenski, I., Rus, D., 2022. MapLite 2.0: Online HD Map Inference Using a Prior SD Map, IEEE Robotics and Automation Letters, Vol. 7, No. 3, 8355-8362

Ding, S., Fu, Y., Wang, W., Pan, Z., 2021. Creation of high definition map for autonomous driving within specific scene, International Conference on Smart Transportation and City Engineering 2021, SPIE,

Elghazaly, G., Frank, R., Harvey, S., Safko, S., 2023. High-Definition Maps: Comprehensive Survey, Challenges, and Future Perspectives, IEEE Open Journal of Intelligent Transportation Systems, Vol. 4, 527--550