Semantic-enhanced personalized route planning for smart mobility

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***Abstract*—Traditional routing systems rely on lowest-cost path computations, with mostly static and very coarse modeling of user preferences and road characteristics. This paper presents a framework for personalized route planning enhanced by semantic reasoning. It extends the open-source Valhalla routing engine with ontology-based knowledge representation and automated reasoning to support dynamic route customization based on road, user, vehicle and context features. Experimental validation demonstrates the feasibility of the proposed approach.**

***Index Terms*—Industry track, route planning, automated reasoning, Web Ontology Language, smart mobility, personalization, Valhalla, OpenStreetMap**

I. Introduction

Navigation services are essential in daily mobility, but most routing engines still compute the shortest or fastest path without considering users' individual preferences or fine-grained road characteristics. This limitation is particularly evident in urban scenarios, where route suitability often depends on user's driving attitude, vehicle features and context information. More detailed modeling can enable not only greater personalization in personal navigation systems, but also path planning customization in additional scenarios, including *e.g.*, (i) power and charging management for electric mobility, (ii) cultural or natural beauty tours, (iii) hiking and trekking.

Recent studies are integrating knowledge representation and reasoning into route planning for more intelligent and context-aware navigation. In [1] an ontology-based algorithm captures and reuses taxi drivers' experiences within a ubiquitous environment. Route data are collected via a mobile app, and segment traversal frequency is used to build a cost model. The system computes optimal paths using Dijkstra's algorithm over a weighted graph and stores each resulting route in a Web Ontology Language (OWL) ontology, distinguishing between driver- and algorithm-generated paths, while also considering traffic conditions. This enables adaptive routing and knowledge reuse in future queries. A recent OWL ontology [2] models human factors for route planning with autonomous vehicles. However, the ontology is not aligned with existing cartographic data models, making reuse of existing maps more difficult; furthermore, the proposed ontology-based path planning case study is simulated manually, with a software implementation left for future work.

Autonomous driving for terrestrial vehicles, robots and Unmanned Aerial Vehicles (UAVs) is a further key scenario for semantic-enhanced route planning. A semantic navigation system for mobile robots [3] uses ontological reasoning to map high-level goals to physical locations. The inferred location is then passed to standard path planning algorithms. Similarly, in [4] a mobile robot platform annotates sensor data to determine context for high-level destination selection, while conventional routing is exploited at low level. Inference for Point Of Interest (POI) discovery and a conventional open-source routing engine are coupled in [5], leveraging semantically annotated map data to compute accessible routes for users with motion disabilities. Nevertheless, frameworks for deep integration of reasoning within path planning algorithms are not available yet.

This work presents a semantic-enhanced routing framework extending the open-source *Valhalla* (https://github.com/valhalla/valhalla) engine. It integrates an OWL domain ontology, derived from the *OpenStreetMap (OSM)* data model, and logic-based inference to compute dynamic, personalized costs for each road segment. The architecture supports user-defined semantic profiles, enabling rich, customizable routing based on road conditions, infrastructure, or personal constraints. A case study within the Italian territory validates the approach from performance and correctness perspectives.

The remainder of the paper is structured as follows: the proposed framework is described in Section II, and a case study is presented in Section III to highlight the system's potential. Final remarks follow in the conclusion.

II. Proposed Framework

The proposed framework, shown in Figure 1, extends the open-source Valhalla engine with logic-based reasoning capabilities, integrating the *Cowl* [6] OWL manipulation library and the *Tiny Matchmaking Engine (Tiny-ME)* [7] inference engine. This grants compatibility across platforms ranging from cloud to edge and mobile computing. The framework adopts a modular client-server architecture and preprocesses OSM data to construct a tile-based road graph. Unlike traditional engines that minimize only distance or time, the system dynamically adjusts segment costs through semantic inference over an OWL Knowledge Graph (KG), supporting user profiles for personalized context-aware routing (steps 1–4 in Figure 1). The KG encodes road features extracted from OSM maps –*e.g.*, surface type, road type classification, traffic signals, and intersections– as well as user profiles in an OWL

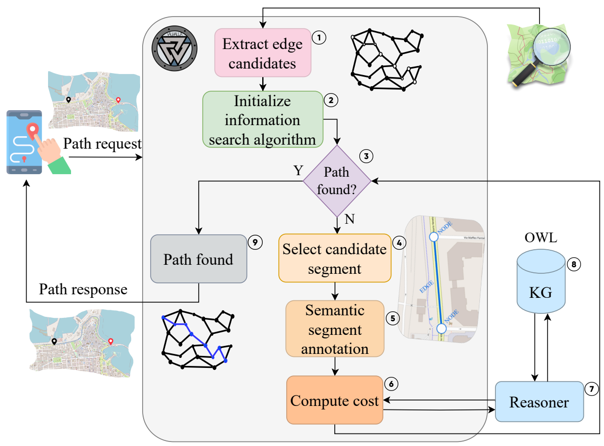

Fig. 1. Semantic-based path computation workflow.

2 fragment, corresponding to the Attributive Language with unqualified Number restrictions ($\mathcal{ALN}$) Description Logic (step 5). User profiles include general routing preferences – *e.g.*, avoiding highways or intersections, a liking for tunnels or suburb routes, *etc.*– and context-aware features, which could be derived from physical or affective state, vehicle sensor data, *etc.* Road segments are edges in the graph representing the overall map of the area. Upon route request, for each segment under evaluation, the system employs *semantic matchmaking* leveraging *Concept Abduction* and *Concept Contraction* non-standard inference services [7] to assess a *semantic distance* between user profile and road segment characteristics (steps 7-8). This becomes the edge *cost model* used in the Valhalla path calculation algorithm (steps 6-9). A peculiar benefit of the proposed approach is symbolic logic-based *explainability* of outcomes [7], which can justify the path selection in a comprehensible way and thus increase users' trust in the system.

III. Early Evaluation

To validate the proposed framework, experiments have been carried out using synthetic routing scenarios throughout the Italian territory. The KG has been derived from preprocessed OSM road network data enriched with semantic annotations. A total of 466 routing requests have been extracted from a uniform sampling of the *Italy routes* dataset in the Valhalla distribution: each route involving two geographic locations has been associated with a semantic user profile drawn from a (statically) created set in the KG. All routing computations have used *car* mode. Tests have been performed on an Ubuntu 22.04 LTS virtual machine with 6 virtual cores and 12 GB of RAM, hosted on a system featuring an Intel Core i9-11900F CPU and 64 GB of RAM. Each routing request has been executed in a separate *Docker* container to ensure isolation and cold start. Mean response times are 688, 792, 1482 and 1899 ms for routes in the 1-50, 51-100, 101-500 and 501-1000 km distance ranges, respectively, with memory usage always below 90 MB. Manual qualitative inspection has evidenced overall correctness of the computed routes w.r.t. requests.

IV. Conclusion

This paper has presented a semantic-enhanced route planning framework for personalized smart mobility. The proposal integrates the Valhalla routing engine with an OWL-based knowledge model and logic inference capabilities through the Tiny-ME engine. Personalized routing is achieved via a semantic cost model that dynamically adjusts path selection based on user-defined preferences. Early experimental results on real OSM data for the Italian territory has demonstrated the feasibility of semantic customization, showing that user preferences such as surface type or infrastructure features can effectively guide routing decisions. While the integration of reasoning services introduces moderate computational overhead w.r.t. Valhalla's default cost model, the system maintains acceptable response times improving the alignment between computed routes and qualitative user constraints.

Future work will concern road segment caching strategies to reduce reasoning latency, the enrichment of the ontology with additional mobility descriptors, and the support for multi-modal routing scenarios. Dynamic profiles annotated from vehicle On-Board Diagnostics (OBD) data and user's wearable devices will be integrated. The framework will be evaluated in live urban, extra-urban and mixed contexts with real user profiles to assess its practical effectiveness and adaptability.

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