Image Segmentation Procedure for Mapping Spatial Quality of Slow Routes

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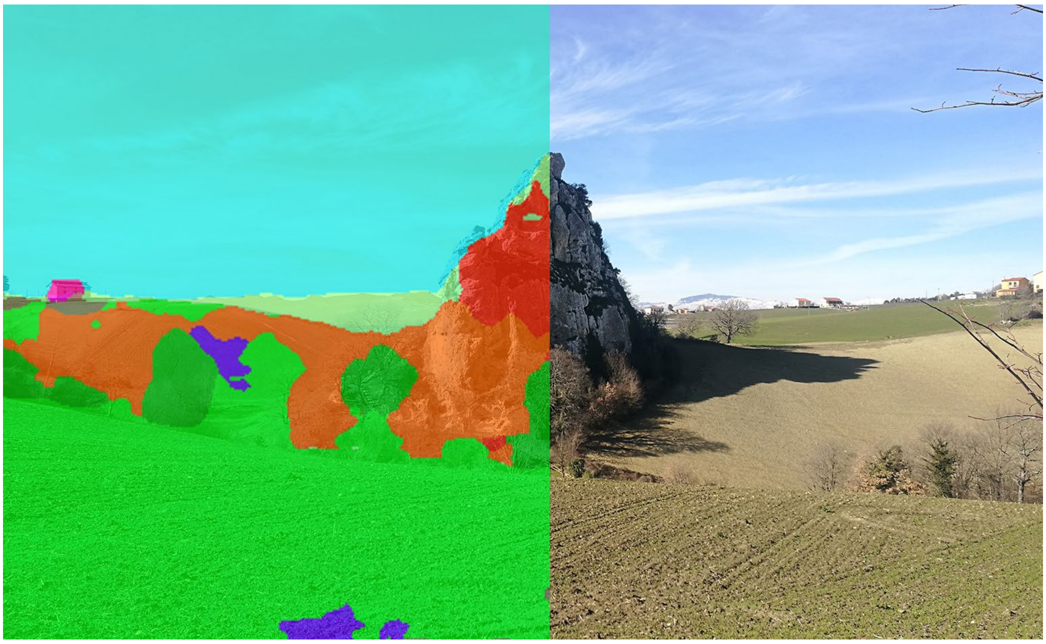
Abstract

The current research aims at investigating the potential of Image Segmentation (IS) as a data source for mapping, with a bottom-up approach, the spatial quality of slow routes, localized in the territories "in-between" the main cities. The paper analyses two different case studies in Lombardy and Molise regions, where a different territorial configuration and data are available. The IS method, that computes area percentages in the street-level imagery by using Pixellab/TensorFlow digital environment, has been applied for detecting three different environments that are intersected by the selected routes and that are also detectable by using GIS tools: open spaces, built environment and rows of trees. These have been considered as relevant since they affect the users' perception of the places in a different way. The research points out how the IS method can be complementary to the GIS-based detection method to collect more detailed geo-information about the places, but also a very powerful tool to catch geo-information by the street-level imagery, in the territories where no thematic geospatial data are available.

Keywords
image segmentation, mapping, spatial quality, slow routes, fragile landscapes.



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Introduction

The method of analysis illustrated in this contribution starts from the assumption that the quality of the experience one feels when crossing a landscape is influenced by the presence of some components of the landscape: open spaces, which guarantee wide views, presence of tree-lined rows that make the route pleasant to follow, proximity to villages and isolated architectural elements, that attract our attention. Of course, the mere presence of these elements does not in itself constitute the general quality of the landscape, but their identification is at the same time crucial in order to then establish, in a second phase of investigation, the specific quality of its components. The survey method was applied in open contexts, where it is more difficult to recognize the elements of value that can be used to determine the best route, as it allows you to pass near the most prestigious places and to cross more pleasant landscapes. It was decided not to apply the method within the main built environments, as geo-referenced information is usually more available within them that can be used to identify the most interesting and preferred path. The method therefore aims firstly to establish criteria for the choice of the slow path of higher spatial quality in the landscapes in between the main urban centers. The method refers to procedures of mapping, meant as a specific creative process for the definition of maps which we consider here as a sort of output of the mapping [Abrams, Hall 2006] through methodologies that are able to accept at the same time information of an objective nature, which adopt a point of view that is not only conceptually external, on the part of experts (or so called outsiders), according to a top-down logic, integrating them with more subjective information, related to the perceptual sphere and according to a logic capable of receiving contributions from users (insiders), according to a bottom-up logic. This methodology has already been developed in previous research experiences, in particular on the topics of the Spatial Quality Index of Slow Routes (SQISR) [Scandiffio 2019], of mapping with image segmentation analysis with identification of significant elements using Mapillary Segmentation [Bianchi et al. 2020; Rolando et al. 2021] and here a more precise definition of the method in landscapes where no GIS top-down information is available and how to implement them with bottom-up techniques.

Case Studies: the Monks Route in Lombardy and the Parco delle Morge Cenozoiche in Molise

The research has been applied to two case studies, characterized by different territorial configurations. The one in Lombardy region is about the Monks Route, a slow route, which connects the Milan city center to Corte Sant'Andrea, by crossing the Po Valley in the north-west to south-east direction, following the Lambro river valley. This route is 64 km long. For most of its length, it crosses open spaces, characterized by a flat agricultural landscape in the southern agricultural park of Milan, which is spotted by historical abbeys (e.g. Chiaravalle and Viboldone), rural hamlets and farmhouses, which are settled along with a network of canals that support agricultural cultivations. This contribution focuses the attention on the route stretch between Civesio and Viboldone hamlet, 1.5 km long, where it is possible to cross three kinds of environments such as open spaces, built environment and rows of trees, which are of interest for the purpose of the current research. The map shows the whole itinerary between Milan and Corte Sant'Andrea, where the Monks route connects to the Via Francigena (Fig. 1a). The other maps show the selected area along the route, localized in the surroundings of the Viboldone Abbey, where the IS methodology has been tested (Fig. 1b). The map also shows the selected geo-localized pictures, taken along the route, which have been used to recognize spatial components of the landscape by the street-level imagery (Fig. 1c).
The second case study is located in the Parco Cenozoico delle Morge in Molise. The landscape where the Morge park is located straddles the valley floor of the Biferno, which crosses the Molise Region, and the Trigno river, which separates it from the Abruzzo Region. The park network crosses the territory between the two arms of the Celano-

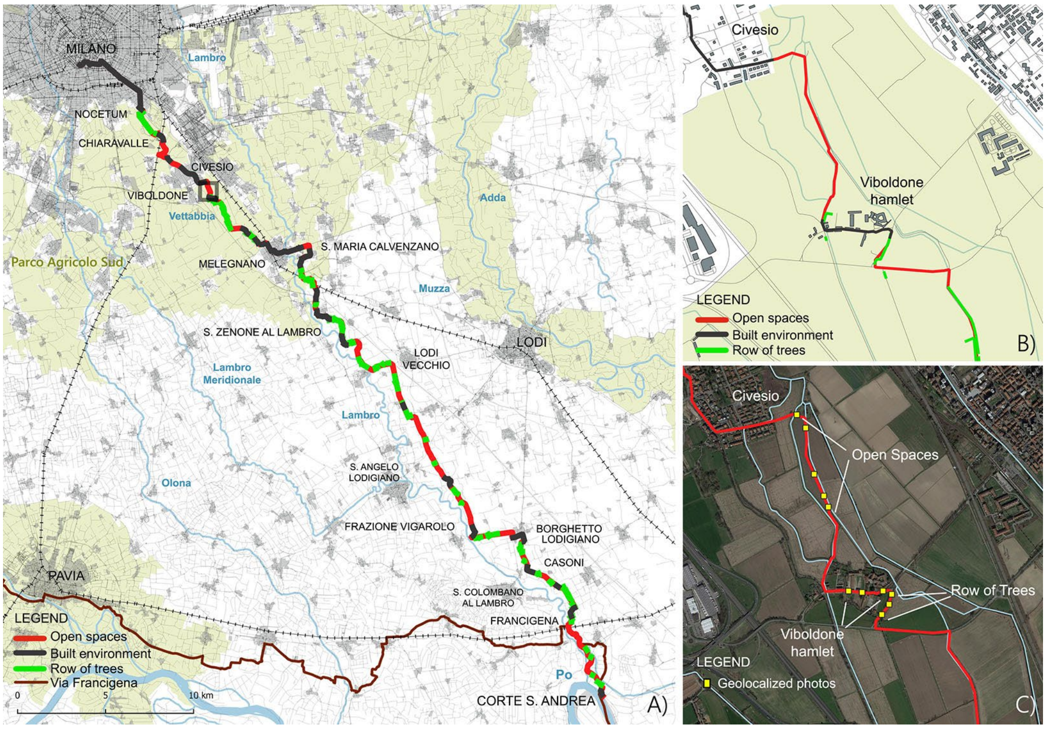

Fig. 1. a) Map of the whole Monks route, which highlights spatial components of the landscape along the route; b) Map highlights the selected area in the surrounding Viboldone Abbey; c) Map shows the selected geolocalized photos in the selected stretch.

Foggia Tratturo, which connects Abruzzo and Apulia. The choice of this area was determined by the presence of a route that crosses the area and enables the discovery of the park, characterized by a hilly landscape, large open spaces, spotted by small historical hamlets. In terms of the availability of thematic geospatial data, the area is characterized by the absolute lack of them, which do not allow a top-down analysis of the area. At the time of writing, the Molise Region has not developed detailed cartography of its territory; therefore, the maps (Fig. 2) have been extrapolated by OpenStreetMap geographic database. The route under study is part of a 75 km itinerary through the Park area [Carulli et al. 2021]. The selected area is extended between Pietracupa hamlet up to Morgia di Pietravalle and it enables crossing the three selected types of environments (open spaces, built environments, the row of trees). The map also shows the geolocalized pictures, taken along the route (Fig. 2b).

Methodology

The methodology of this work stems from the need to assess the quality of the landscape crossed by slow mobility routes, by trying to maximize the data available in the different territories under analysis. It is useful, therefore, to consider different layers of analysis that work in synergy for this purpose, respectively GIS databases and street-level photographic surveys. On the one hand, the top-down analysis with GIS mapping techniques has been performed on the basis of geospatial data availability (Regional portals and open data portals), in order to map the three kinds of environments along the selected routes. The GIS approach, by exploiting the zenithal point of view, which is typical of the maps, enables the mapping of landscape features on large scale contexts. The measurement of the spatial quality of slow routes through GIS has been successfully tested in the area crossed by the Monks route by the SQISR method, by exploiting the potential of geodatabase [Scandiffio 2019]. In the framework of the current research, the GIS approach has been applied to map the three selected landscape features along the Monks route, by using the available datasets on the Lombardy Geoportal. By applying GIS geoprocessing tools, the graded track of the Monks route has been drawn. The track highlights, on the whole route, the

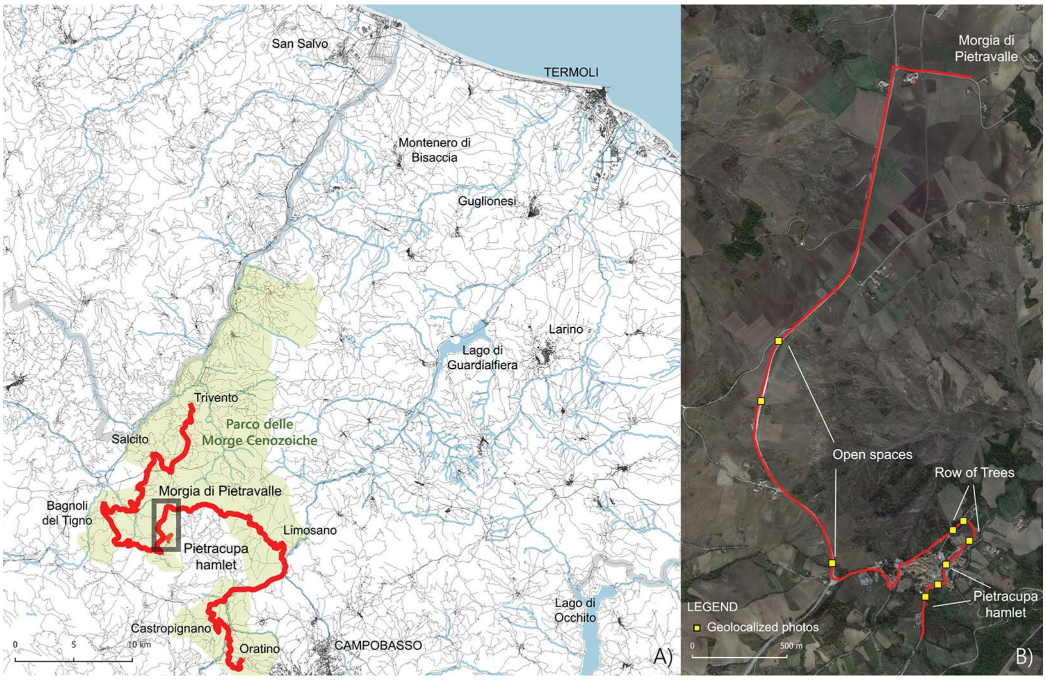

Fig. 2. a) Map of the whole route between Oratino and Trivento in the area of Parco delle Morge Cenozoiche, in the Molise region; b) Map of the selected area between Pietracupa and Morgia di Pietravalle, which shows where the pictures are taken.

spatial distribution of open spaces, built up areas and rows of trees along the route (Fig. 1a). In the Molise Region, it has not been possible to perform the GIS approach through the SQISR method, due to a lack of geospatial data. In this perspective, the big amount of georeferenced street-level imagery, available through the web by Google Street View [Dragomir 2010] or Mapillary [Warburgy 2018] is a big data source [Zhang et al. 2018], for detecting the landscape features along the route from the users' point of view, and also for generating geospatial data on the map.
In this sense, the current research explores the methodology that uses the street-level photographic survey as a basis for the analysis of the territory by Image Segmentation (IS) technology. This system is part of the broader ecosystem of Machine Learning (ML) and allows the automated identification and perimeter of different elements within a photographic shot. A Mapillary photographic survey [Porzi 2020] was used for both study areas for this work. The choice of Mapillary is due to its flexibility in the acquisition of images along chosen routes. Compared with Google Street Map, it is possible to choose every kind of routes, even off-road tracks, and they are available for further analysis right after uploading. Mapillary enables the making of fixed-distance photographic sequences by choosing the distance in-between two consequent photos, showing the exact location and the length of the space crossed.

Unfortunately, a recent update in Mapillary API has disabled IS analysis, which has been the basis for previous work [Rolando et al. 2021; Yang et al. 2022]. Therefore, a different digital engine has been experimented. The snapshots extracted from Mapillary were then processed with the Python library Pixellib [Olafenwa 2022], which allowed the identification of the percentage of image occupation of the elements in the ADE20K dataset [Zhou 2018]. All the elements present are listed for each image, ordered by decreasing percentages of occupation of the total space. Each image has been associated with one of the three environments based on the fundamental elements present and their quantification. The detection of the elements enables the evaluation of the scene from a landscape point of view; they are the only ones to be considered because they are present in quantities greater than 15% and are: sky, building, road, tree, hill, field.

The presence of a very high percentage of the sky element is decisive for the detection of the open spaces. Other elements present in this environment are road, field, and hill.

This element is also of fundamental importance in an absolute sense to quantify the visual field's opening within the limits of correct framing of the photographic survey. In the specific case, the evaluation of photos with a sky presence of more than 60% is discarded due to obvious operator errors in framing. The sky element, mainly detected in extra-urban environments, is always present in the other two environments but it is discarded when the other fundamental elements are present at the height of more than 25%. The built environment is intuitively characterized by the presence of the building element, which clearly identifies the inhabited centers; in the row of trees environment, the presence of the tree element is instead predominant. The methodology explained above was applied to the two case studies by analyzing individual shots taken along the two routes, in Lombardy and Molise, respectively, and analyzed by using the IS digital ecosystem. The methodology has been applied to the Monks route, in the stretch near Viboldone Abbey (Fig. 1c). In this portion, photographs already present in the area were used, located in the open space, in the Viboldone hamlet, and along the avenue bordered by the row of trees immediately beyond. The map shows the spatial distribution of the photographs. From the overall sequence of photographs available through Mapillary, five significant shots were selected for the open spaces environment because of the long stretch and three exemplifying shots for the other two environments (Fig. 1c). A similar approach would have been used for the area in Molise, however, the lack of both cartographic and photographic material led to a customized application of the explained methodology. A photographic survey was carried out with the Mapillary platform along the route through the village of Pietracupa to the Morgia di Pietravalle. The photographic survey [D'Uva 2022] was carried out by taking pictures every 5 meters, divided into two tracks of 300 and 184 photos respectively. The selected geolocalized pictures are visible on the map (Fig. 2b).

Outcomes

The research, by applying IS methodology to the sequence of selected pictures, shows how to identify the average threshold values for each landscape component visible in the imagery (e.g. sky, fields, buildings, trees, walls etc.), which is localized in the selected environment. Within each environment, at least three photographs were selected to which the ML procedure was applied, providing threshold values characterizing the environments in a unique way. In the area of Viboldone Abbey, the open spaces are characterized by the presence of the sky > 50% and the presence of fields > 20% (Fig. 3). Additional elements between 3% and 10% were trees and paths. For the automatic recognition of the built environment, the presence of buildings averaged > 15%, and roads and walls > 30%. Additional elements characterizing this environment are sidewalks, pavements and trees, ranging between 2% and 18%. Finally, the environment characterized by rows of trees is recognizable by an average percentage of trees higher than 40%. In this last environment also the sky can be framed in a range between 30% and 40%.
For the second case study, the Pietracupa area, the open spaces environment, the presence of the sky was detected well over 50%, in addition hills over 20%. Other elements such as road, and trees were detected between 3% and 18%. The hamlet environment is characterized by the predominant building element, over 30%, together with the road element, between 15% and 20%. Finally, the row of tree environment is characterized by the predominant tree element, above 30%. Other detected elements in this kind of environment are road and wall, between 5% and 14%.

Discussion

In the Viboldone area, the comparison between the GIS method and the ML method provides a good match. As it has shown in the previous images (Figs. 1b-1c; Fig. 3), the analysis carried out by GIS, from the zenithal point of view, provides equivalent outcomes

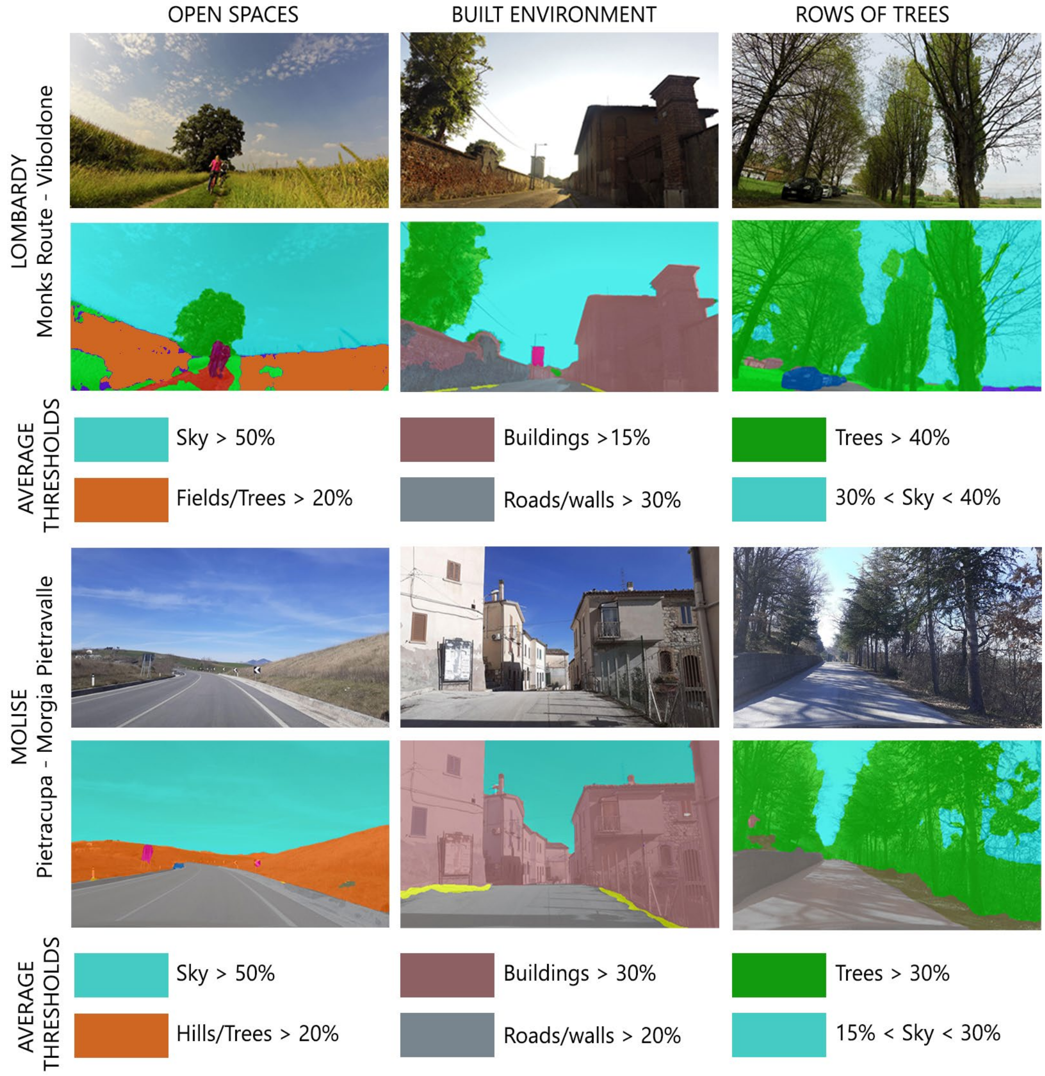

Fig. 3. Analysis of the main outcomes for the selected environments by ML methodology: open spaces, built environment and row of trees. In the case studies of Lombardy and Molise, the methodology provides average thresholds for environment characterization in terms of elements occupation percentage in the imagery.

to the ML analysis, conducted at the street level. In the Lombardy case study, the outcomes performed by the ML method provide precise identification of the environments along the route, as well as they have been mapped through GIS. In this perspective, the street-level methodology seems to be effective to detect the selected environments typologies, even considering the potential of providing much more detailed information about the landscape components (e.g. walls, fences, types of vegetation are very detailed elements, that cannot be detected from the zenithal point of view). Instead, in the area of Pietracupa it is not possible to provide the comparison between the two methodologies, due to lack of geospatial data.
By analyzing the open spaces environment in both case studies, the research finds that the value of the sky element above 50% is a distinctive feature of that space, as well as the sum of the elements fields and trees, or hill and trees above 20%.

In the built environment, it is possible to assume that the building elements plus low percentage of roads, walls, sidewalks are the distinctive features of this environment. By analyzing the both case studies, buildings have different values because of the higher density in the urban fabric of Pietracupa hamlet. To support the measurement of building density contributes the sky value, which is in Pietracupa on average 15%, while in Viboldone, it is 35%. This analysis enables the characterization of the morphological differences of the villages in terms of relationships with the orography of the site, which is different in the case of Pietracupa, where there is a strong acclivity, compared with a predominantly flat landscape in the case of Viboldone.

A necessary but not sufficient condition for identifying the row of trees environment is intuitively the predominant presence of trees. However, their presence alone is not sufficient to characterize the row geometrically as a linear entity along the route. In this case, the digital technology of Instance Segmentation would allow counting the elements in the photos, making evident the differences of the linear vegetation of the row compared to the forest vegetation, which can be considered instead as an aerial entity.

Studies within this work have shown that in order to be able to define the beginning and end of the elements detected with the interpretation of street-level images, it is essential to work on a sequence of images, the distance of which is sufficiently short.

Conclusion and Future Developments

The research has shown the potential of IS methodology as a tool to assess the spatial quality crossed by slow routes as a complementary tool to the GIS or as a source of information when no other thematic geospatial data are available beyond the photographic survey. In this last condition, IS methodology can be used to detect spatial information of the places, with the aim to transpose the surveyed features on the ground to the map, through photogrammetric procedures. In this last operation, it is crucial to take into account the number of shots along the route to get an adequate level of accuracy on the map.
In order to improve the effectiveness of the method for assessing the spatial quality of slow routes, it would be relevant if the specific contributions, related to GIS and IS, are well integrated with each other. In this perspective, a broader integration between both methods, at street-level and zenithal, but also in relation to Remote Sensing [Rui 2018] and to users' contribution (e.g. social networks, big data derived from them, questionnaires) would allow a deeper knowledge of this challenging topic. New research perspectives can be addressed to investigate a better integration between the mentioned methods and mapping techniques.

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