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An approach to street and road network generalization from Graph Theory

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Abstract:

The Transport Network Service in the Spanish National Institute produces and updates road and street network data at the highest possible spatial resolution. This allows to provide exhaustive information to the users of web visualization services, as well as to develop specific applications or analysis that need highly detailed data. However, these data must satisfy the demands of products of varying scales, each with unique generalization needs.

It is essential to ensure that the outcomes of the generalization processes are mutually consistent, and that they are made available to the public at the same time. Until recently, each team responsible for cartographic redaction and design of mapping series at different scales determined how to perform generalization based on their specific needs, expertise, and available tools. This independent approach has proved to be inefficient and has hindered the development of synergies arising from shared requirements.

To address the problem, a dedicated working group was formed to define the requirements for road, street, and trail network data across the national mapping series at scales of 1:25,000, 1:50,000, 1:100,000, 1:200,000, 1:500,000, and approximately 1:3,000,000 for national coverage. The roadmap for this initiative comprises three main stages: first, identifying critical needs based on the number of products they have impact on and the relevance of this impact; second, selecting and labelling the geometries of the original TN according to the scales they influence; and third, developing the processes required to automate the generalization tasks defined in the initial stage.

While the first two stages are quite straightforward, the third one is challenging due to several factors: the vast area (more than 500.000 km^2) and density of the road network; the regional diversity (vast depopulated areas, big conurbations all along the coast, a few big cities inside the Peninsula, and very different patterns of settlements in rural areas); the fact that roads are managed by different administrative governments with different classification criteria; and, finally, the lack of attributes that have speed up or enriched the generalization process in similar projects, e.g. Adolf et al. (2023).

Fortunately, the main requirements are largely consistent across most mapping series and closely align with those outlined in other studies, such as Weiss et Weibel (2014). These include: ensuring a fully connected road network (i.e., no dead ends), preserving the overall structure of the network—applicable also to the street network in products at scales of 1:25,000 to 1:50,000—and applying geometry generalization based on the target scale and feature size. This last aspect is particularly relevant to dual-line road and street segments, roundabouts, junctions, and slip roads, which must be collapsed under specific conditions.

Weiss and Weibel (2014) outline several methodologies for addressing generalization. The first is semantics-based segmentation, which relies on attribute information. In our approach, this method is used to differentiate between roads and streets, as each dataset has distinct requirements. The second methodology is graph-based selection. Among various algorithms, we opted for edge betweenness centrality, which measures the number of shortest paths that pass through a given edge in a graph. This metric has proven effective in identifying street segments that connect roads whose continuity is interrupted by the street network.

The third approach is stroke-based length, which involves grouping segments into longer, continuous lines (strokes) by merging adjacent edges that share nodes, based on the angle between the edges. We apply this method to identify street segments that should be retained to maintain road network continuity and to help preserve the structural integrity of urban areas.

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The fourth methodology involves mesh-based algorithms, as described by Li and Qi (2011). These algorithms select geographic features based on their position within a hierarchical grid that organizes elements according to their size and shape. Features positioned higher in the hierarchy are more likely to be preserved at smaller scales. We apply this technique to detect dead ends in urban environments and to identify segments that can be removed when simplifying areal features, depending on the target scale.

For collapsing dual-line roads and streets, however, we adopt the approach proposed by Zhang et al. (2022), which is based on extracting the skeleton line from the area enclosed between the two parallel lines representing the road or street. In cases involving simple geometries—such as a road widening section on a single-carriageway—the process yields straightforward results. For more complex configurations, we employ Constrained Delaunay Triangulation, as recommended by Zhang et al. (2022), to determine which segments of the resulting skeleton should be retained.

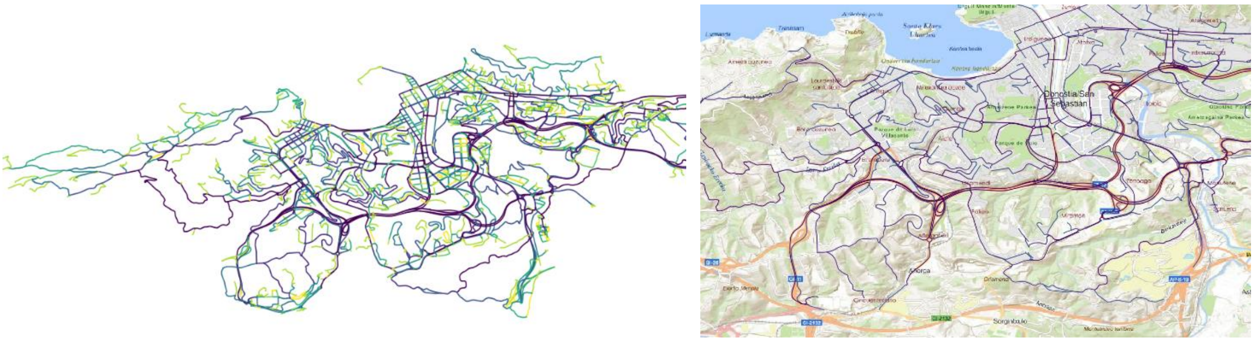

Figure 1. Left: Street network of Donostia (Basque Country), classified by centrality values (darker lines indicate higher centrality). Right: The top 30% of segments with the highest centrality values, overlaid on map services, illustrating that highly central segments may help maintain connectivity between streets and the road network.

Preliminary results appear to be satisfactory when tested in controlled areas; however, robust methodologies must be established before implementing the approach at a national scale. Anticipated challenges stem from the fact that Spain comprises over 8,000 municipalities, each containing multiple population settlements that vary significantly in street network density. This variability can influence the performance of generalization processes—particularly at smaller scales, where only major urban centres should be represented.

Moreover, graph- and mesh-based algorithms tend to perform better in areas with irregular street networks. In contrast, regions with regular grid patterns pose greater difficulties in establishing areal hierarchies, which can hinder the effectiveness of the current methodology. Consequently, it is necessary to investigate alternative algorithms and generalization criteria that consider the characteristics of Spain's diverse urban and rural environments, such as network size, spatial distribution, structural regularity, and street density.

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